Hot Sour Soup: Good for Colds, Bad for Corals

Dr. C. Mark Eakin
NOAA Coral Reef Watch

Wide Range of Coral Reef Threats

1. Human Population Growth
2. Overfishing
3. Coastal Development
4. Lack of Laws / Enforcement
5. Sedimentation (unnatural)
6. Lack of Education
7. Nutrient Enrichment
8. Algal Competition
9. Climate Change / Bleaching
10. Habitat Destruction
11. Tourism
36. Ocean Acidification

2004 Survey: 276 Coral Reef Scientists
Kleypas and Eakin (2007, Bull. Mar. Sci.)

Why Do We Care?

Value of Reefs

- up to $375 billion in fish, seafood, tourism, and coastal protection worldwide $100,000-$600,000 /km^2
- $17 billion in U.S. tourism
- 45 million tourist visits to U.S. reefs
- $247 million in commercial fishing on U.S. reef fish
- 1 billion people rely on reef fish for food
- One of the most diverse systems on earth

Why Do We Care?

Why Do We Care?

www.gefcoral.org

Coral Reefs Under Rapid Climate Change and Ocean Acidification

14 December 2007

O. Hoegh-Guldberg, P. J. Mumby, A. J. Hooten, R. S. Steneck, P. Greenfield, E. Gomez, C. D. Harvell, P. F. Sale, A. J. Edwards, K. Caldeira, N. Knowlton, C. M. Eakin, R. Iglesias-Prieto, N. Muthiga, R. H. Bradbury, A. Dubi, M. E. Hatziolos

Global Environment Facility / World Bank

Coral Reef Targeted Research & Capacity Building for Management

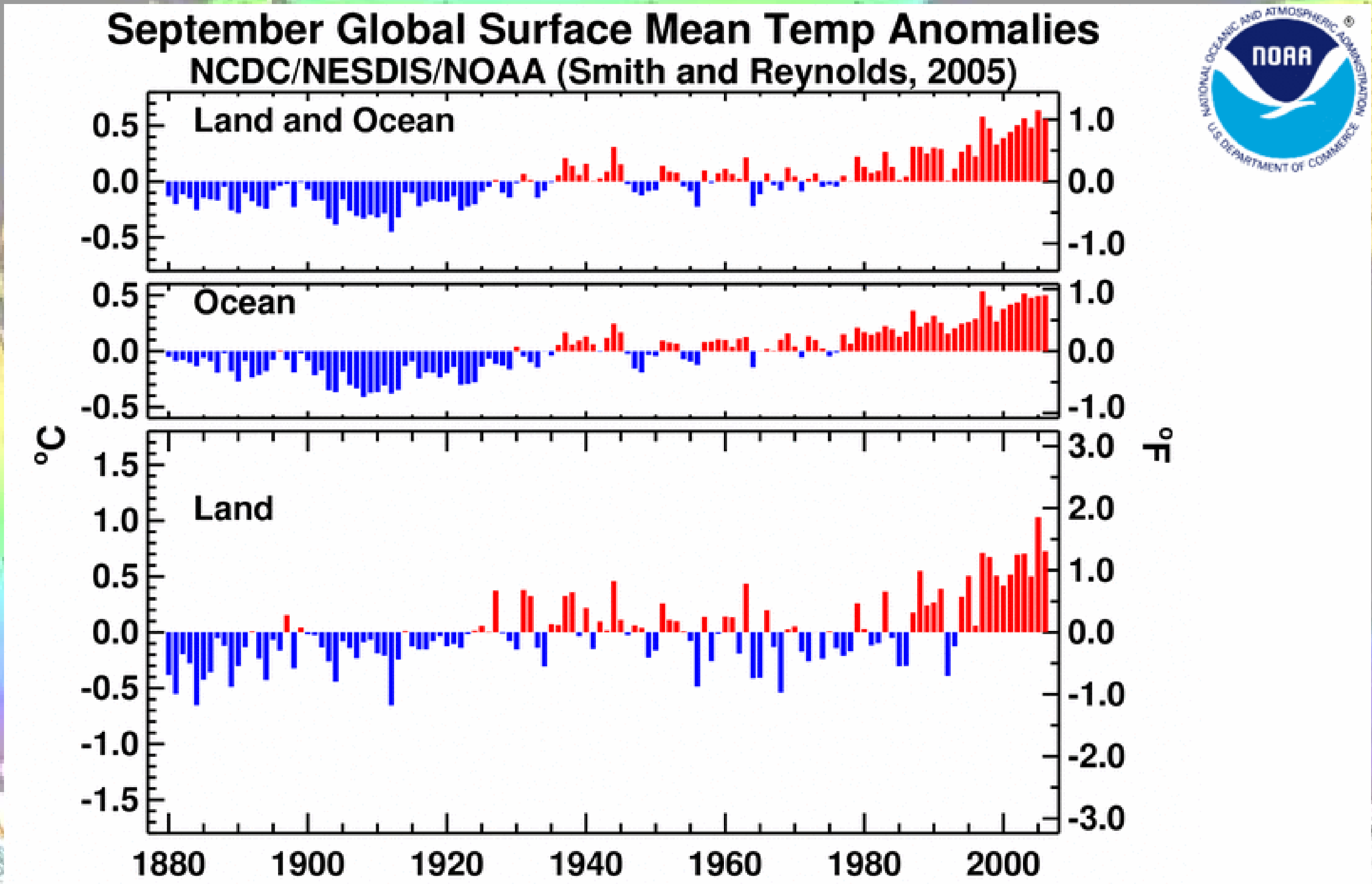
Key Messages:

- Coral reefs threatened by rapid rise in temperatures, ocean acidification
- Likely thresholds of ≈ +2°C, 500 ppm $CO_{2\ atm}$

- Risks are huge
- 2 actions needed <u>now</u>:
  - Reduce emissions
  - Reduce local stress
- There is hope, but we need to work on solutions

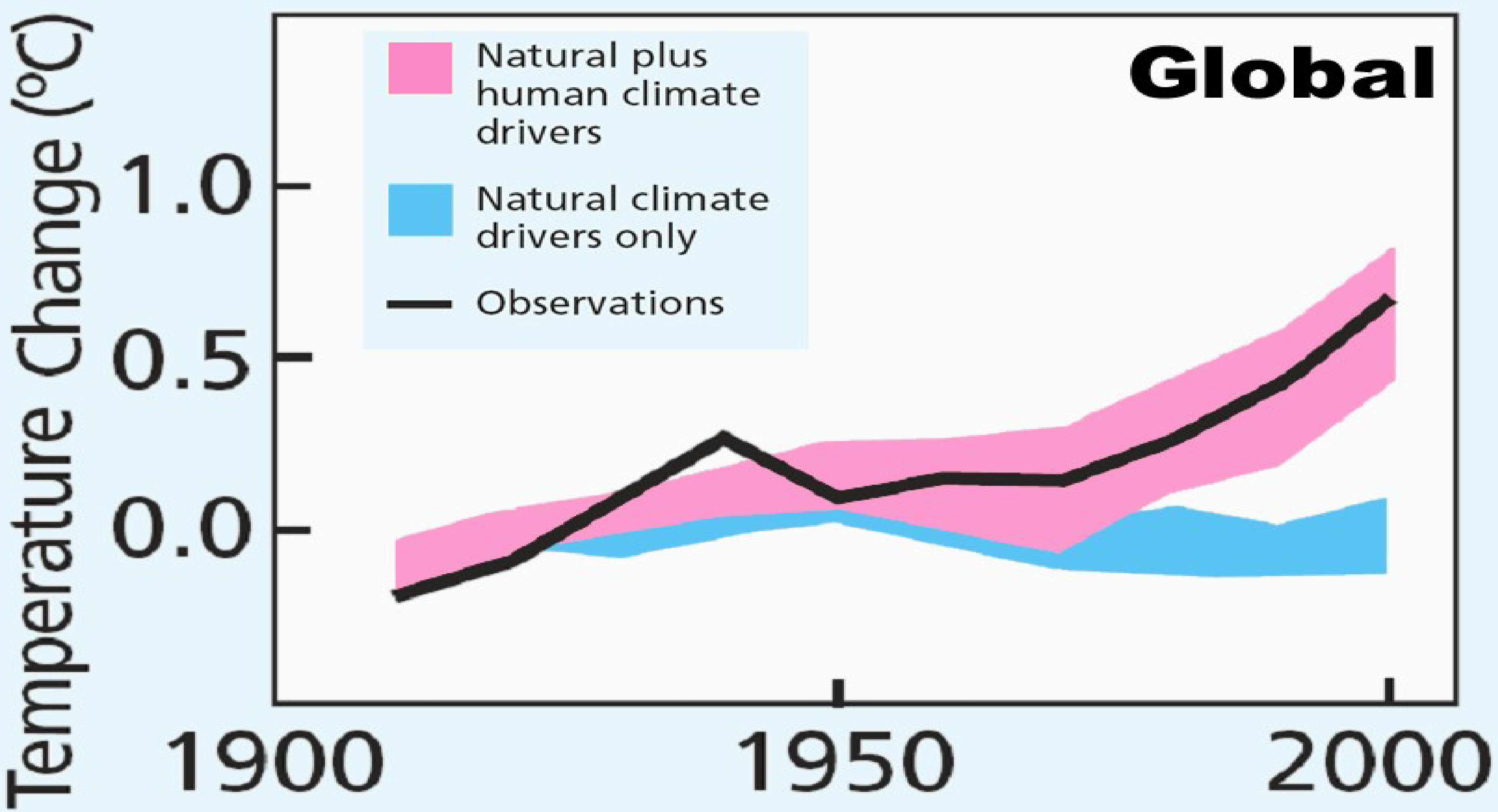
"Warming of the climate system is unequivocal"

- IPPC 4th Assessment Report, WG 1



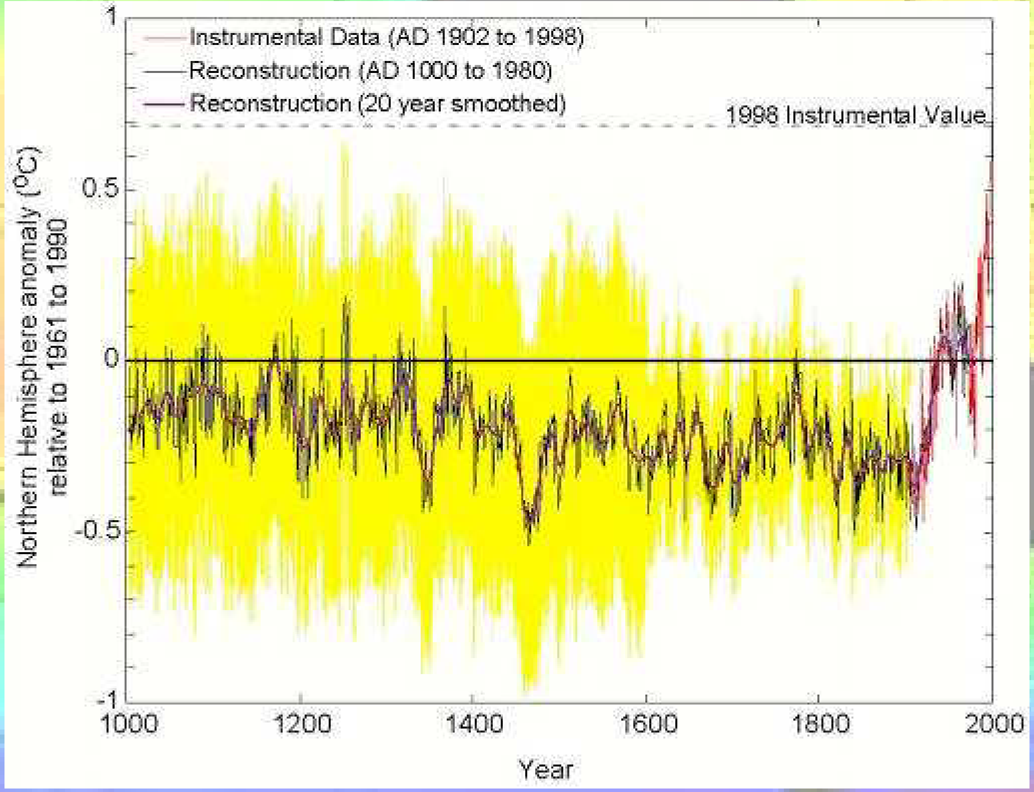
Warming is Primarily Human Caused

"Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic



Is Recent Warming Unusual?

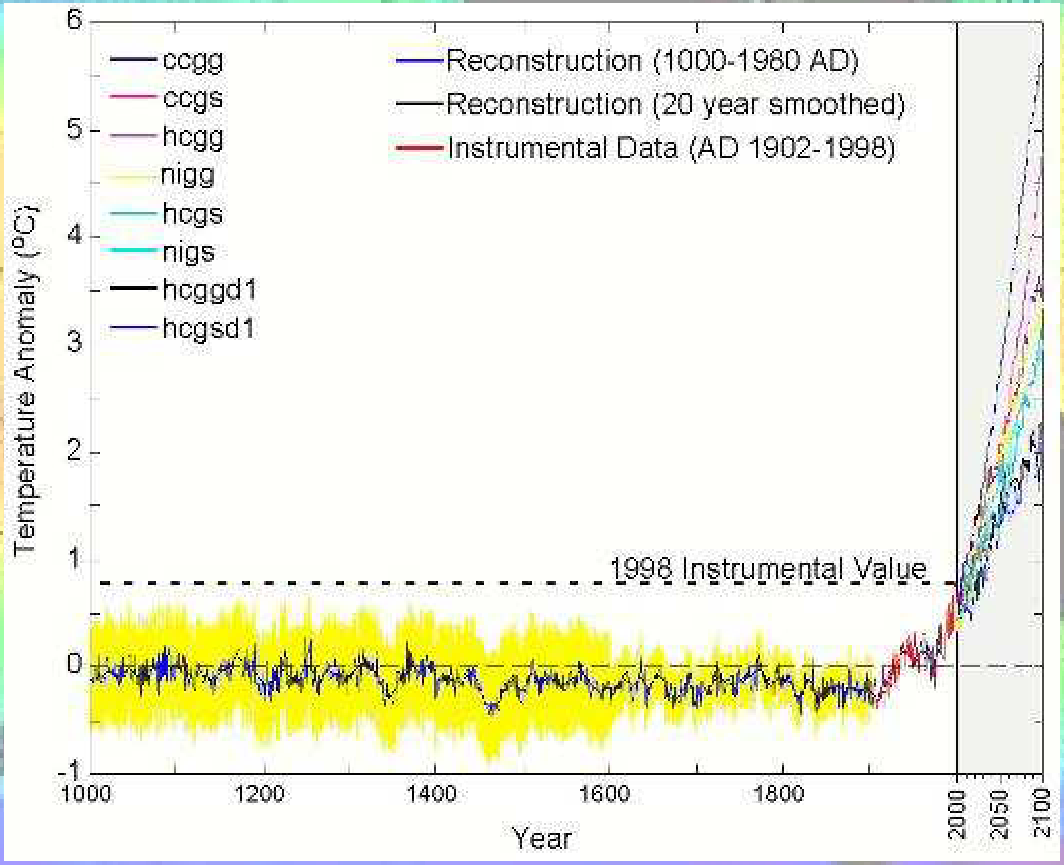
- **Recent warm decades unprecedented in last 1000 years**



After Mann et al. 1999

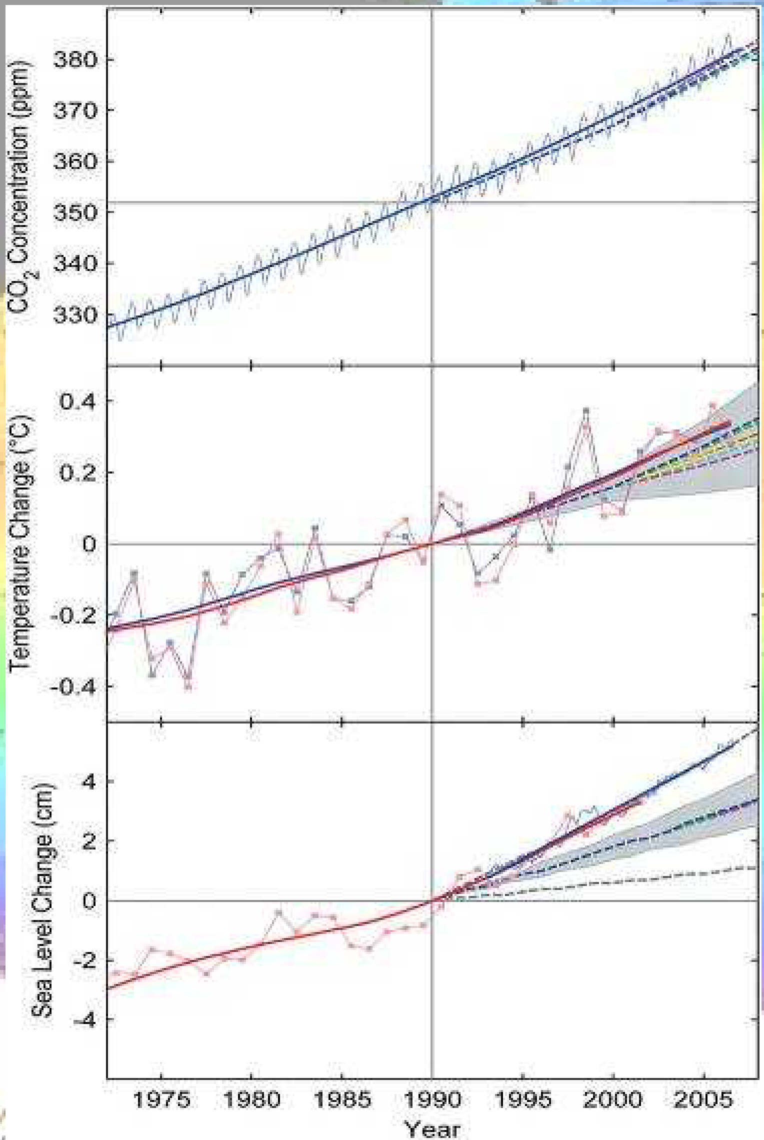
What Does the Future Hold?

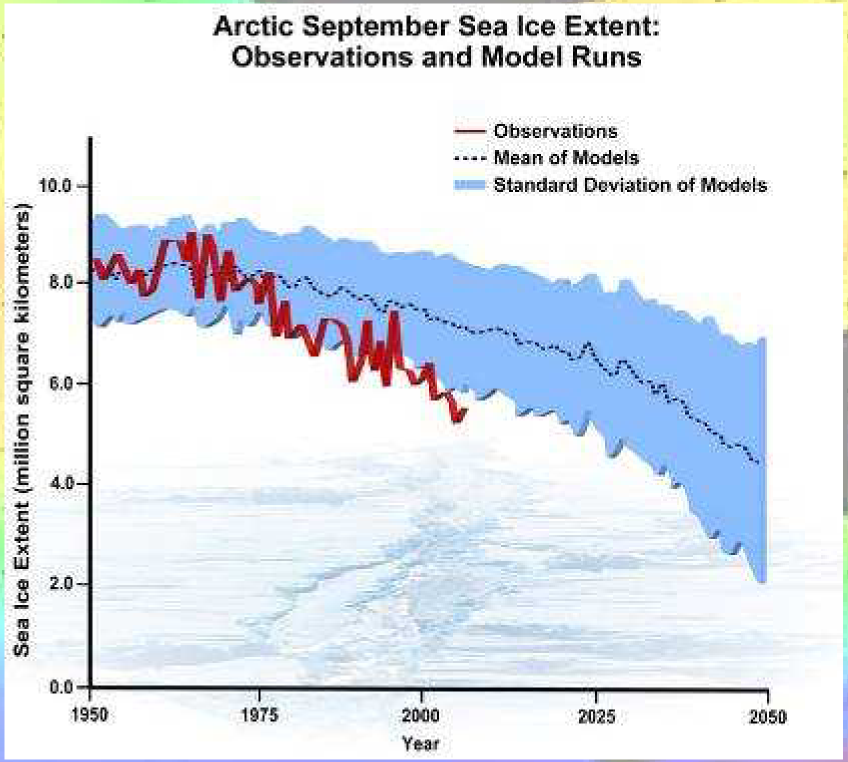
- **IPCC 2000 scenarios compared to last 1000 years**



After Bradley 2000

Reality Following Worst Projections

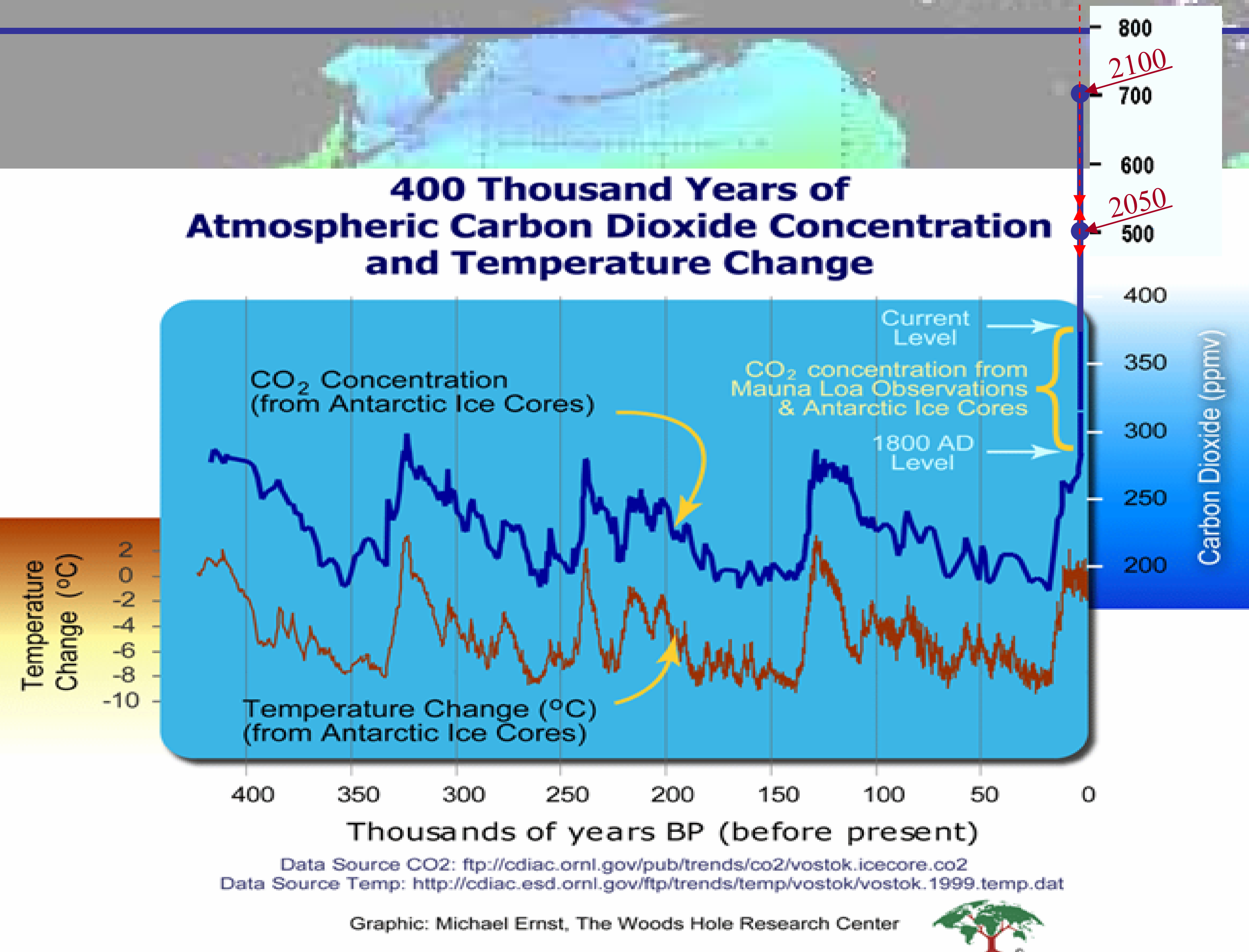




From IPCC 2007 4AR WG-1

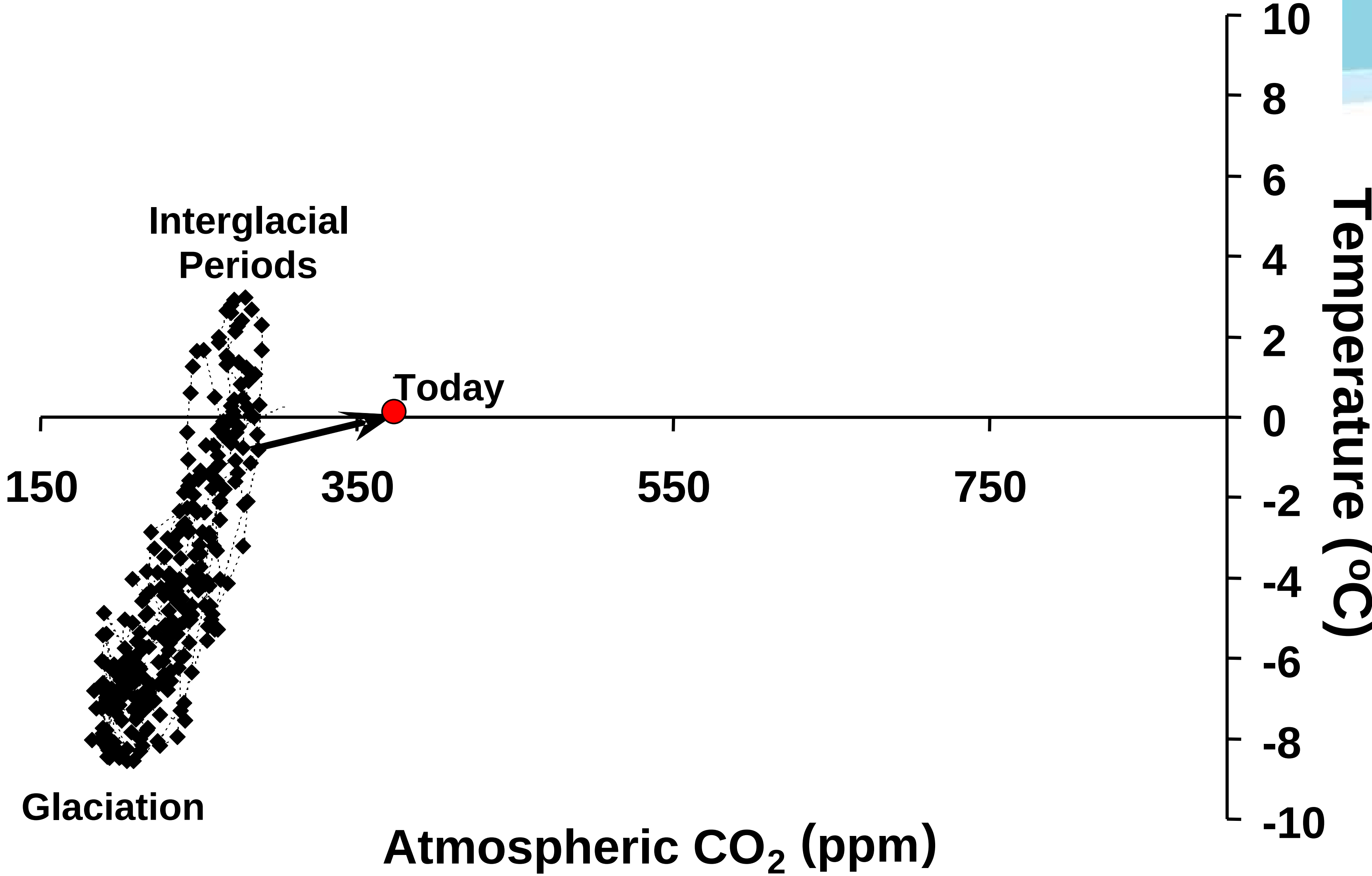
http://coralreefwatch.noaa.gov

Carbon Dioxide and Temperature



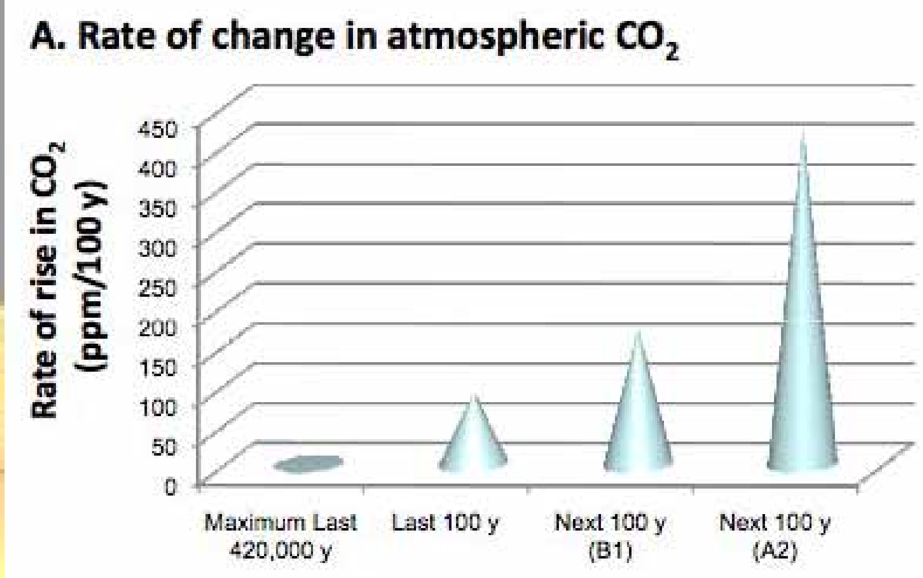
Current CO_2 highest in 650,000 years of ice core data and 24 million years from soil data

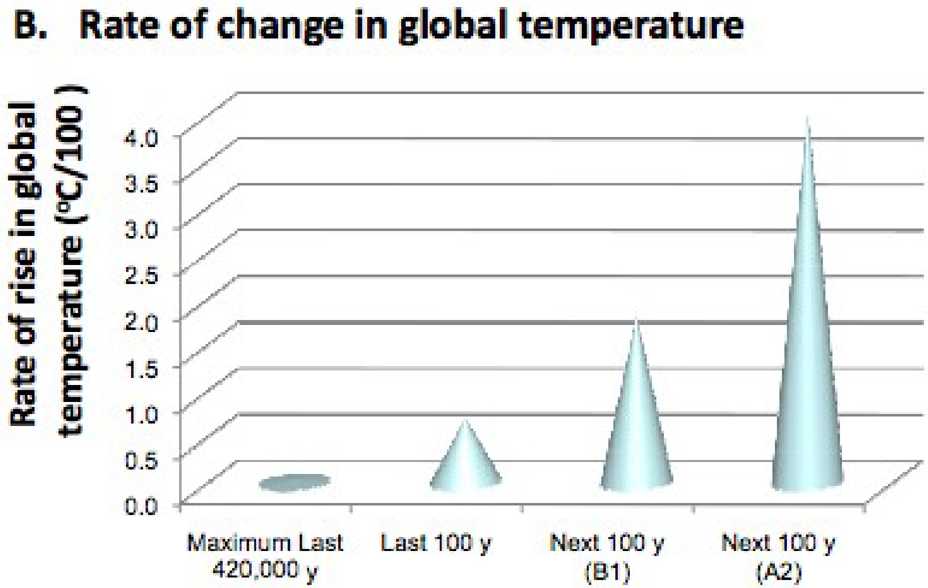
Carbon Dioxide and Temperature



Hoegh-Guldberg et al. 2007, *Science*

Rates are Important





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2004 Survey: 276 Coral Reef Scientists
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What is Coral Bleaching?

- **Most of corals' food comes from photosynthesis**

zooxanthellae

Symbiotic algae

What is Coral Bleaching?

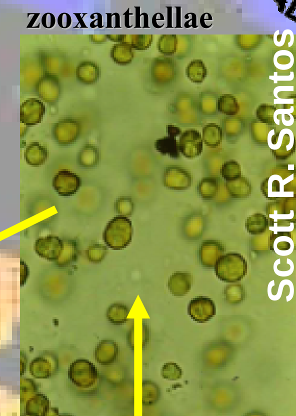
- Most of corals' food comes from photosynthesis

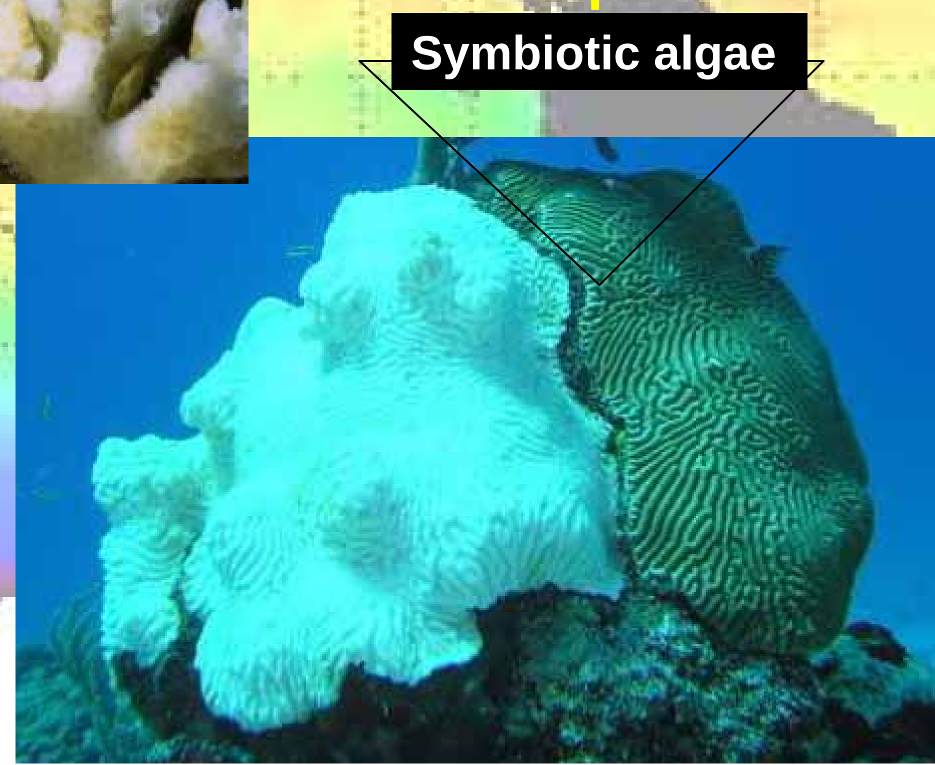
- Corals can "bleach" due to stress

- Corals exposed to high temperatures and/or high light become stressed

- Corals eject their algae; coral appears "bleached

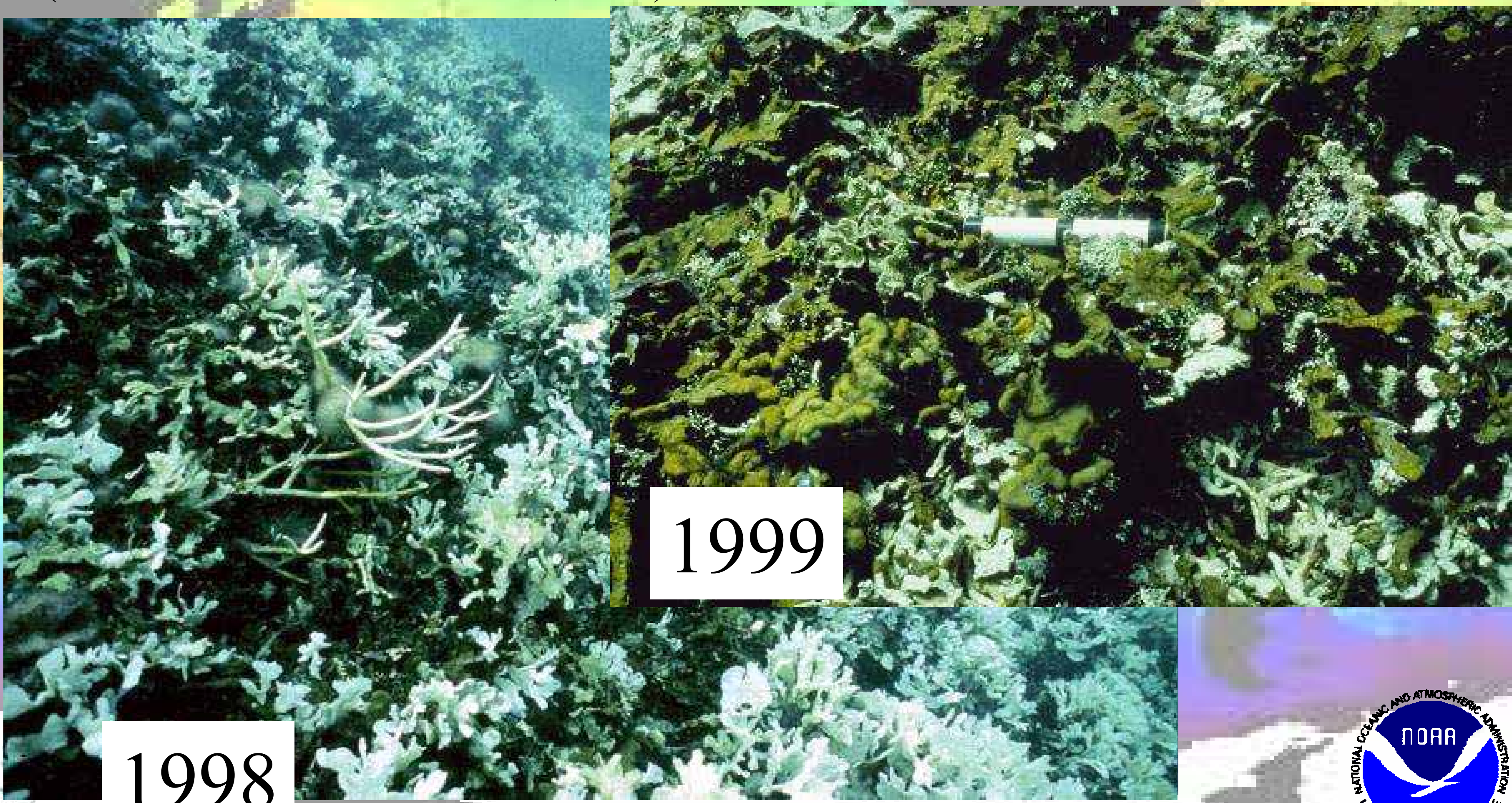
- If stress is mild or brief, corals recover, otherwise they die





Recent Decades: Catastrophic, Unprecedented Bleaching

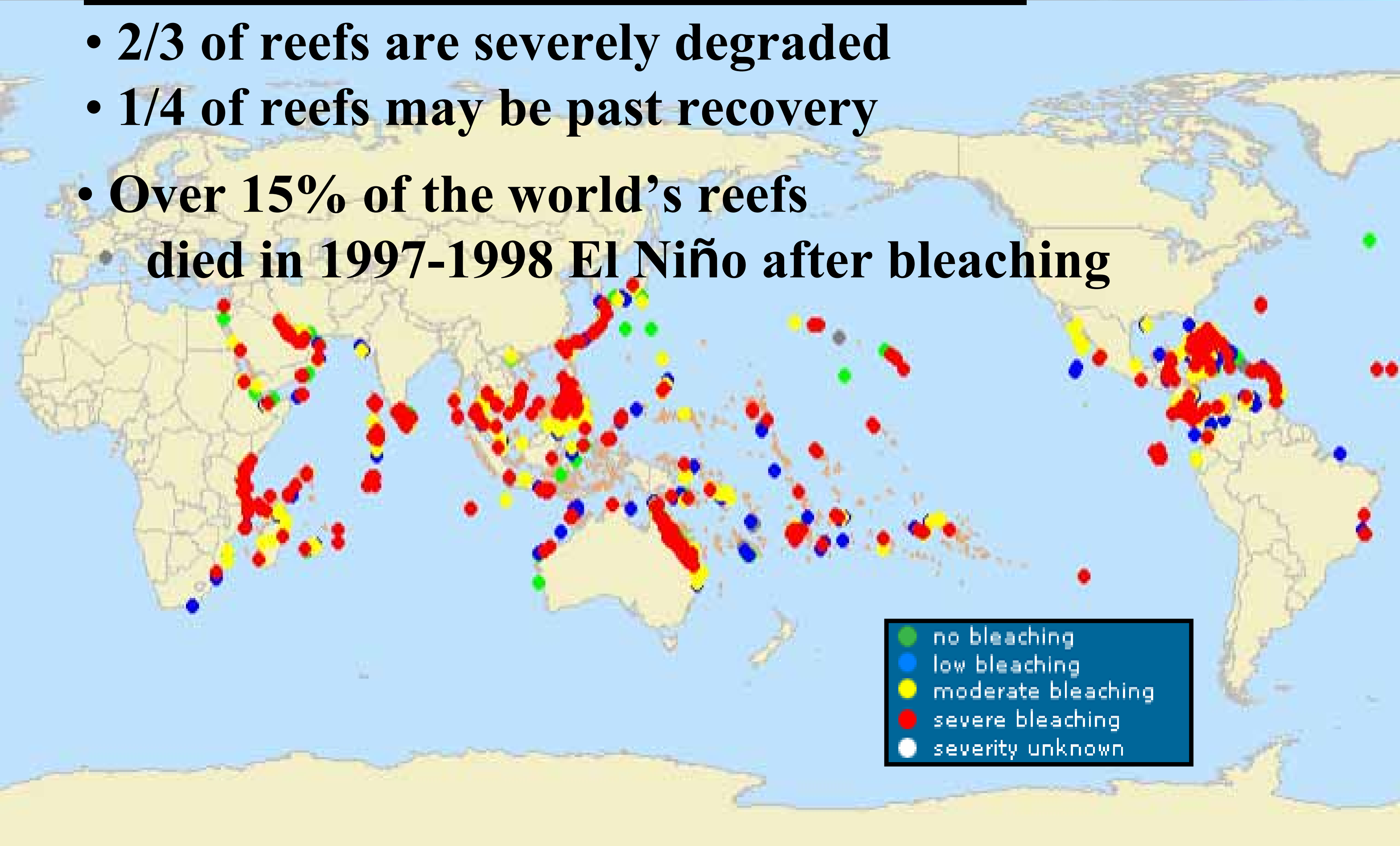
Widespread bleaching in Belize
(from Aronson and Precht 1997, 2001)



Worldwide Reef Deterioration

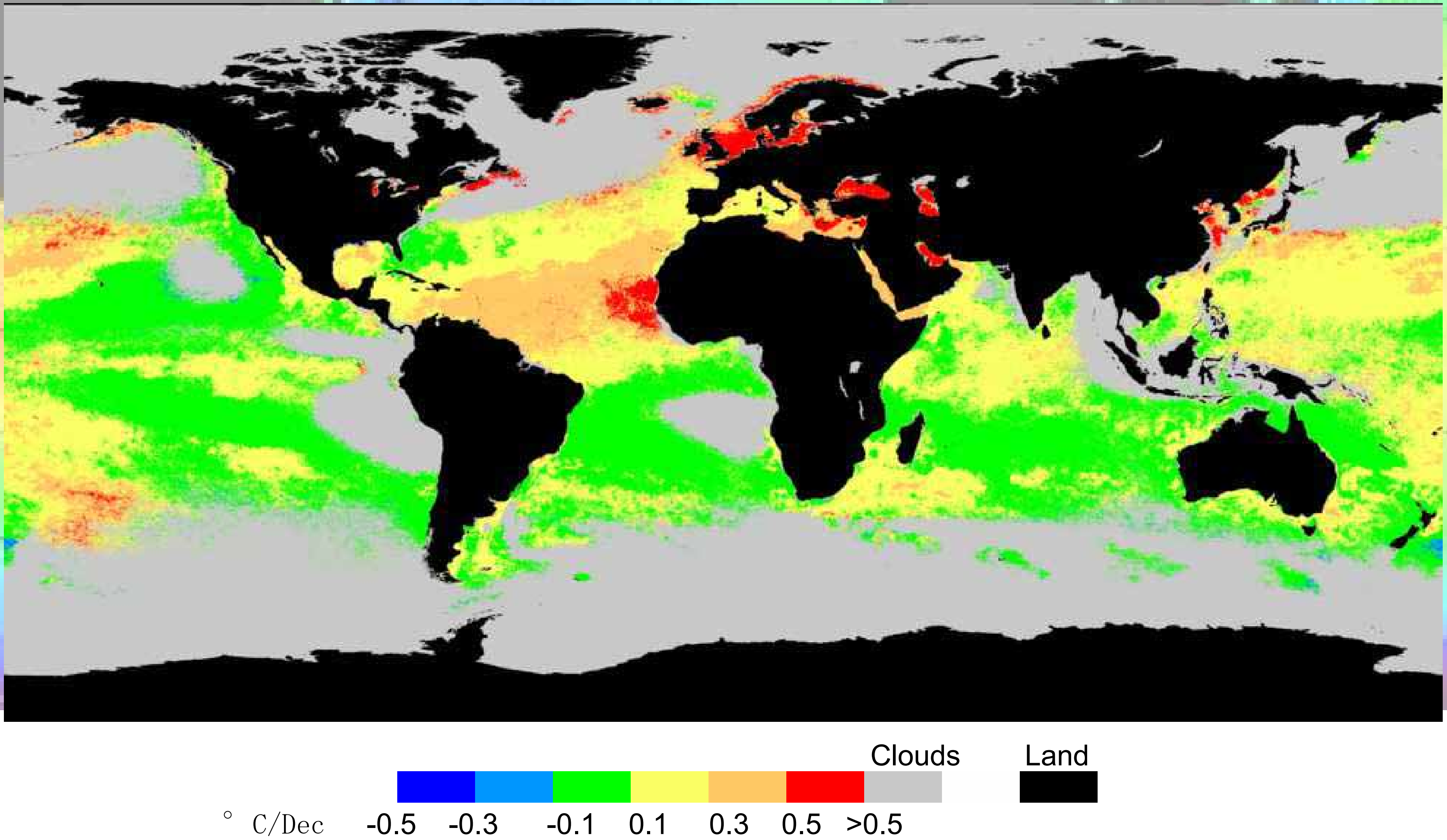
1998 Status of Coral Reefs of the World:

- 2/3 of reefs are severely degraded
- 1/4 of reefs may be past recovery
- Over 15% of the world's reefs died in 1997-1998 El Niño after bleaching

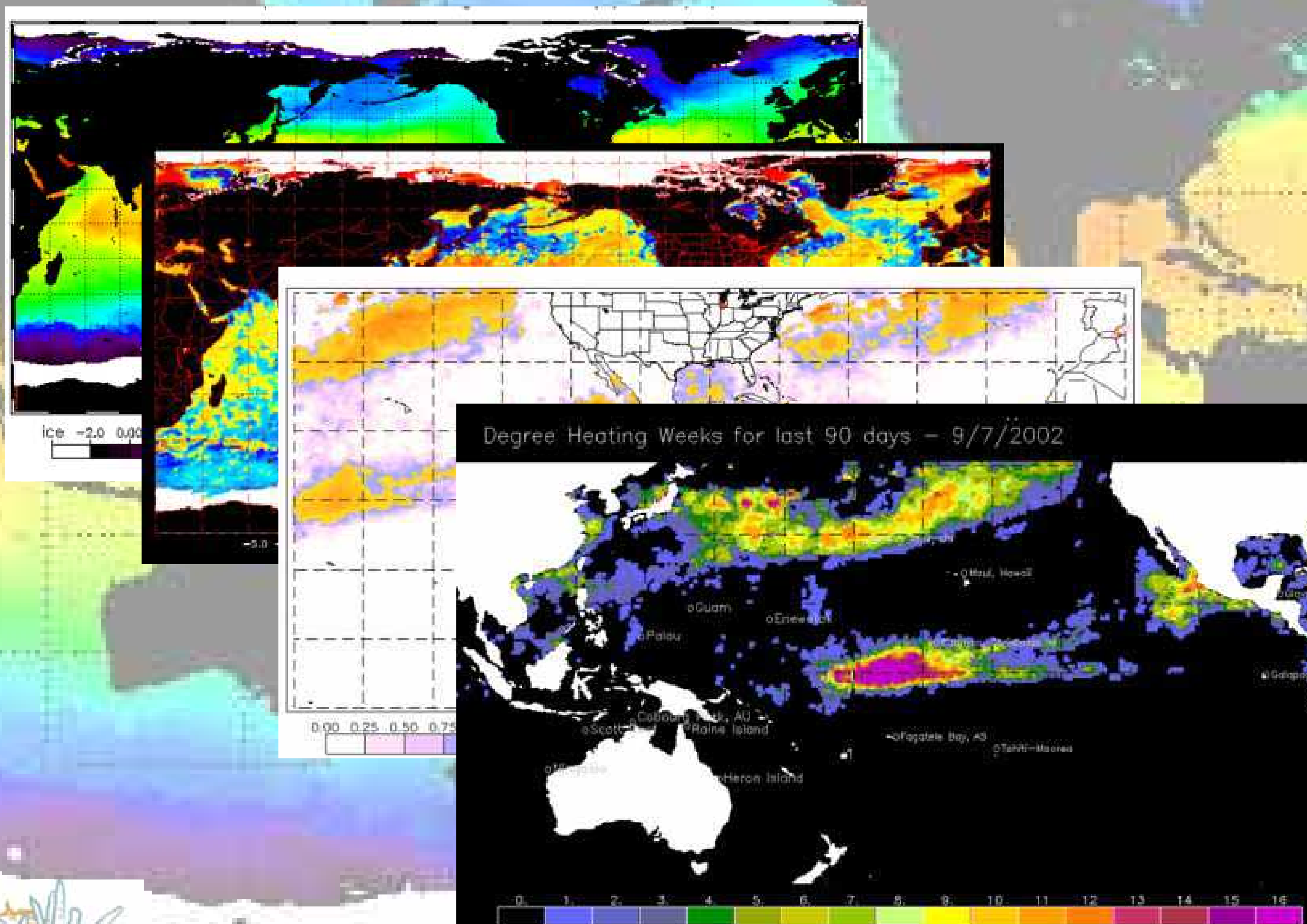


22-Year SST Trends

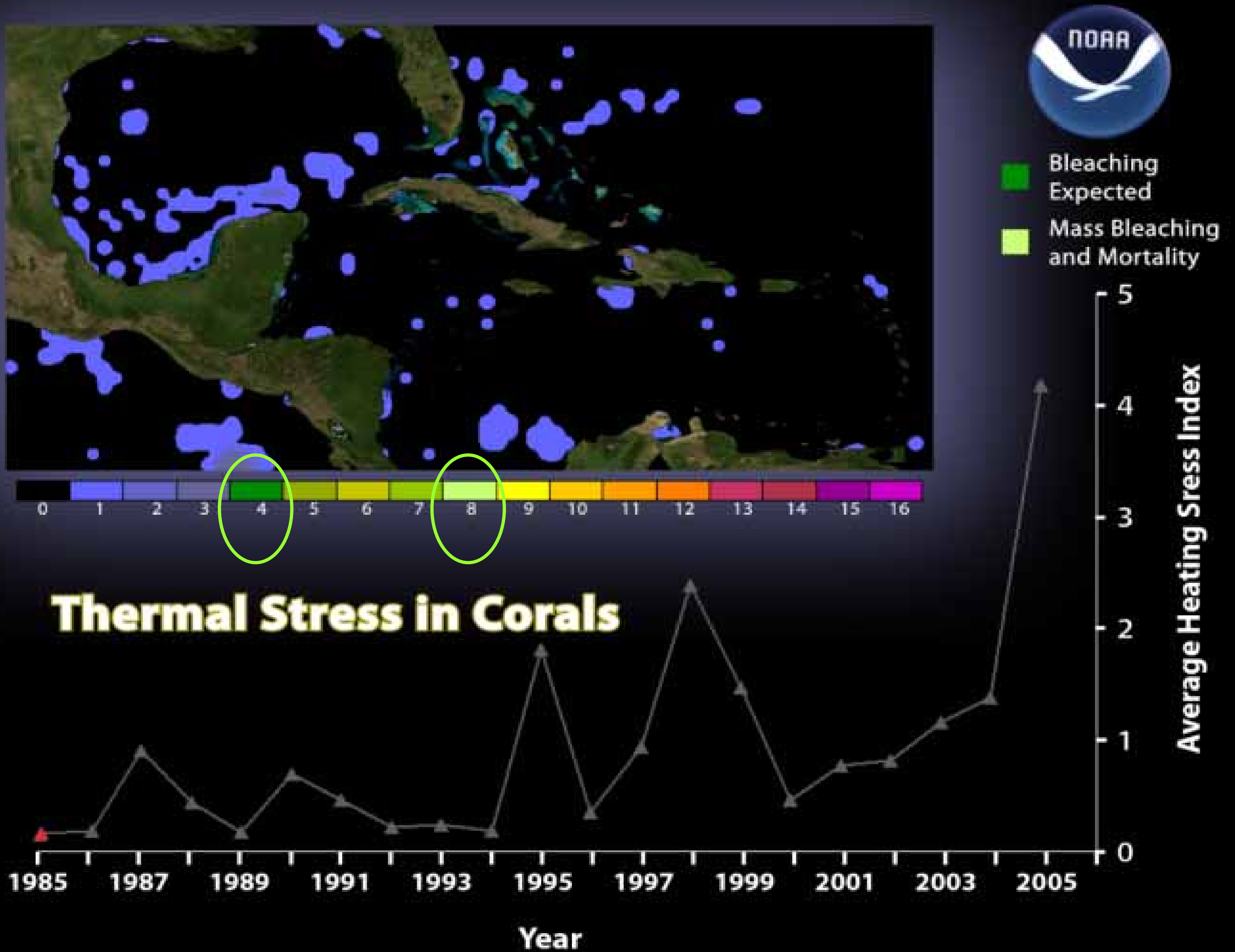
1985-2006



Coral Reef Watch Products



Degree Heating Weeks



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Mass Bleaching and Mortality
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Thermal Stress in Corals
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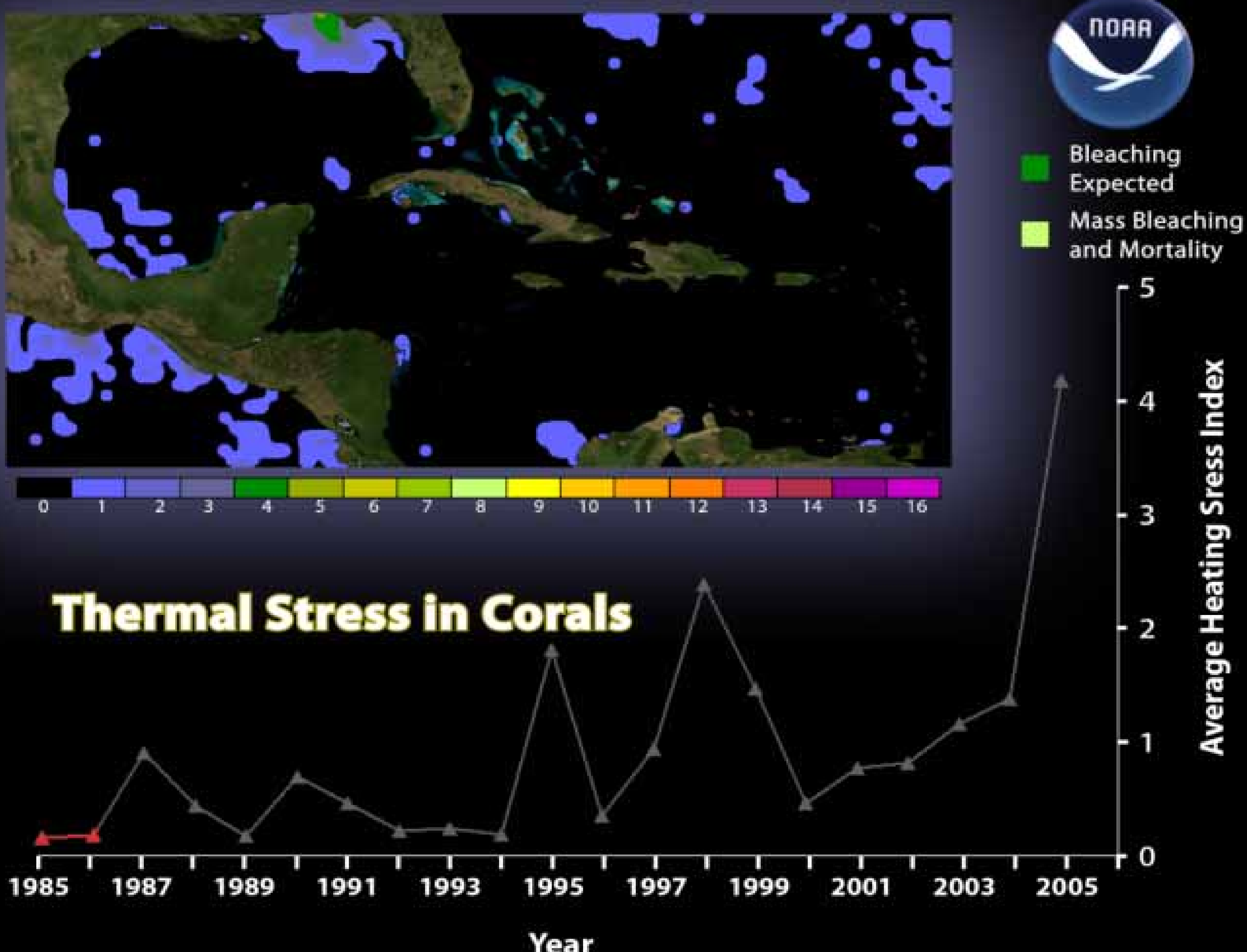

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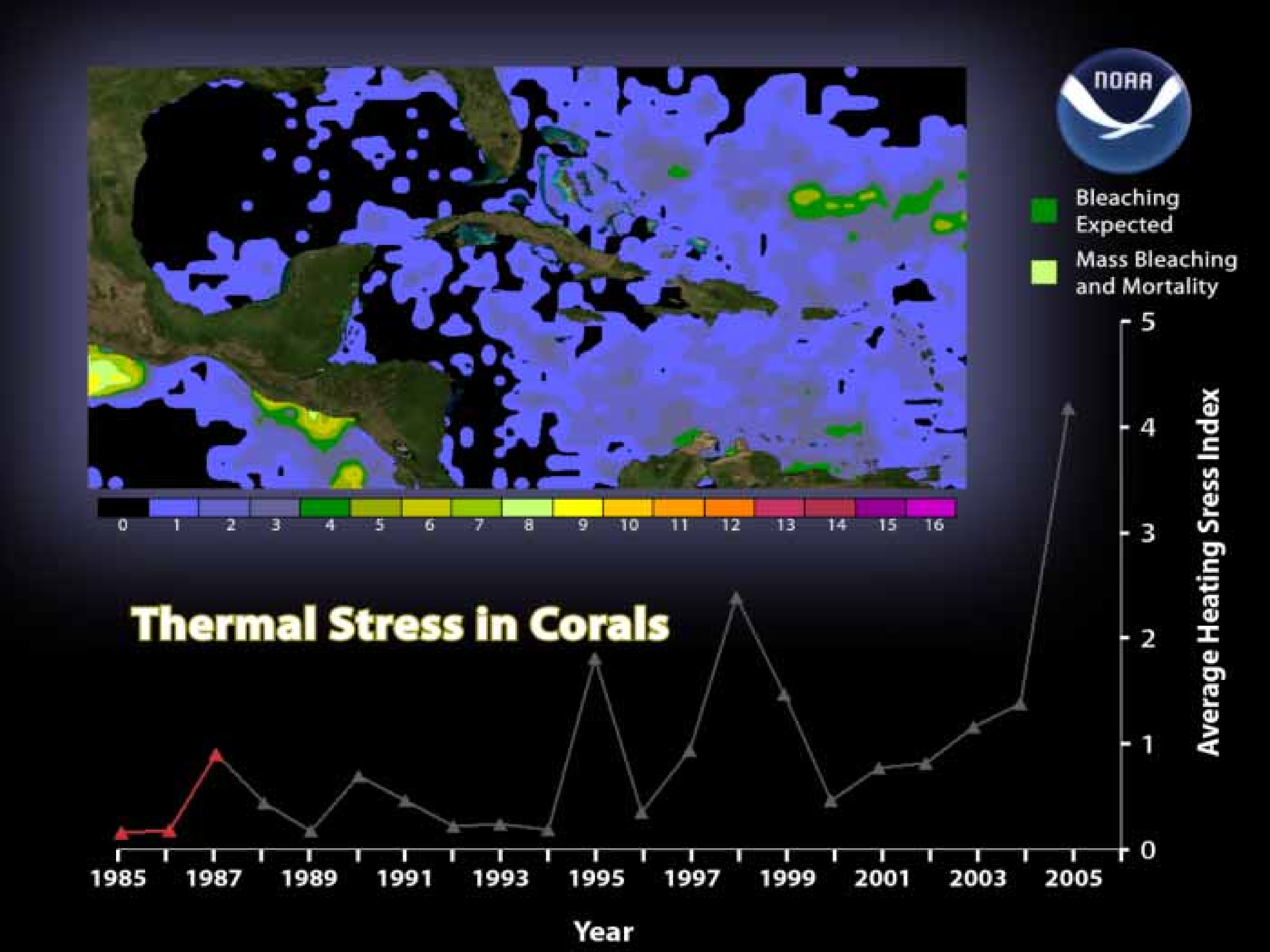
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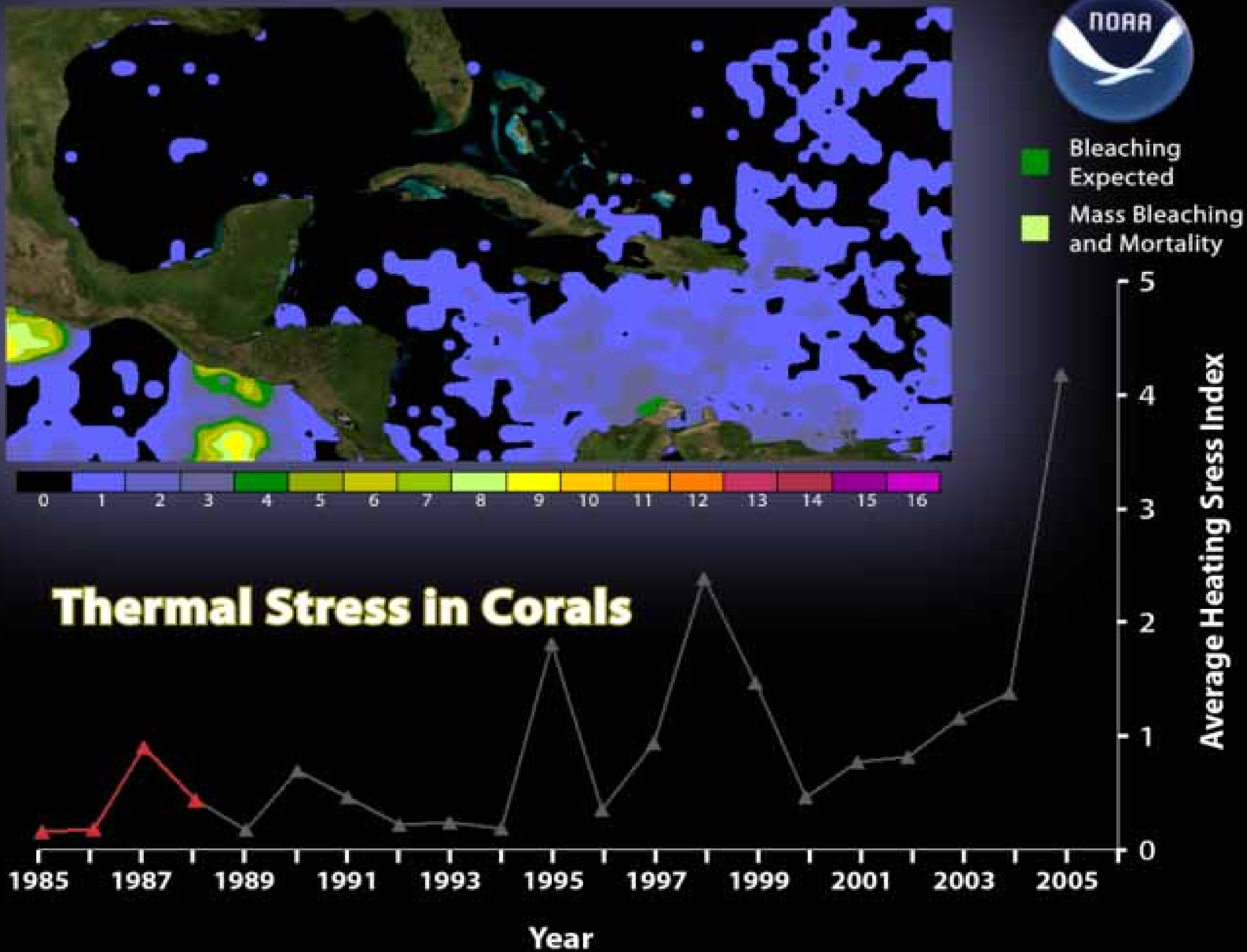

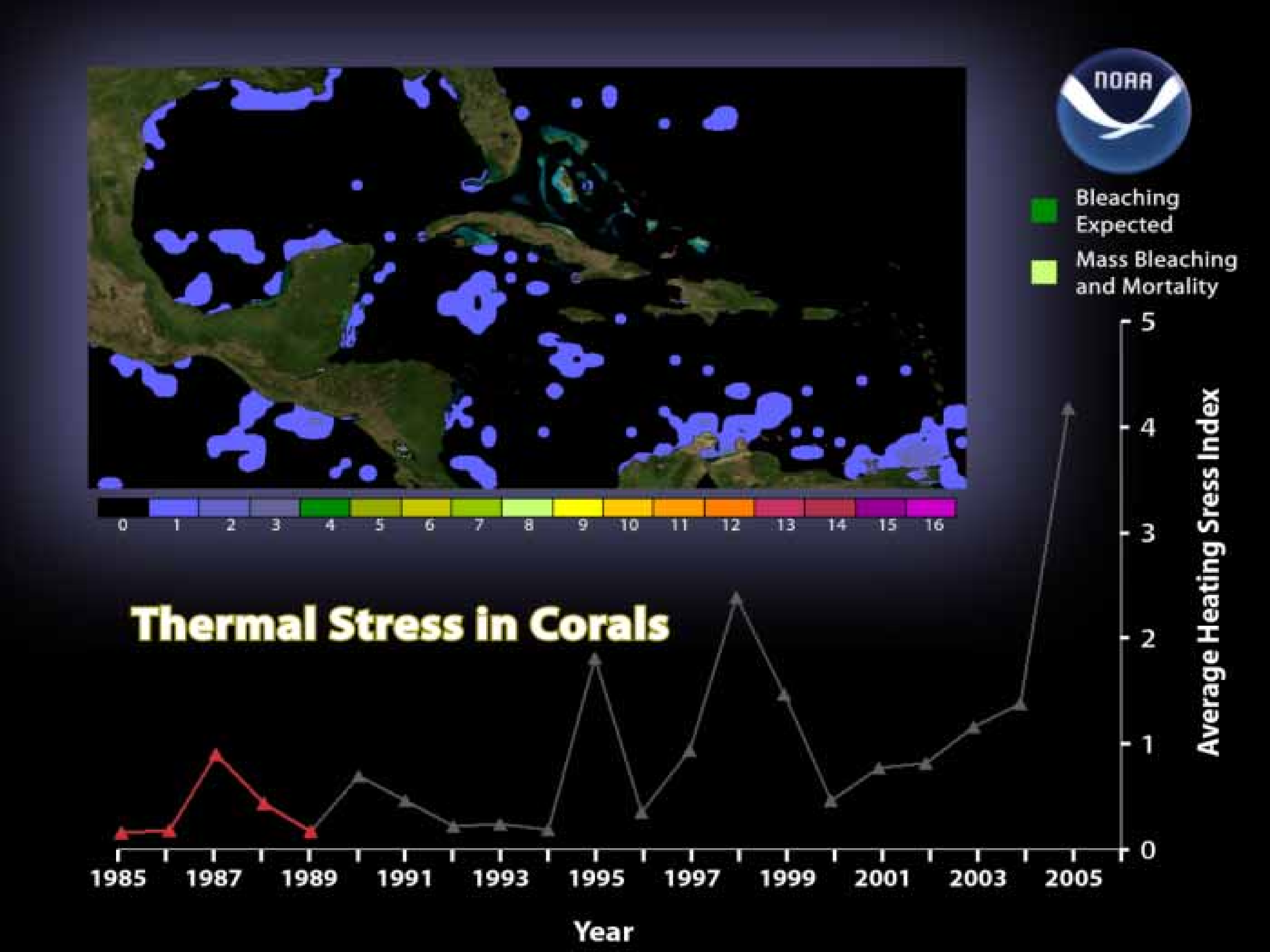

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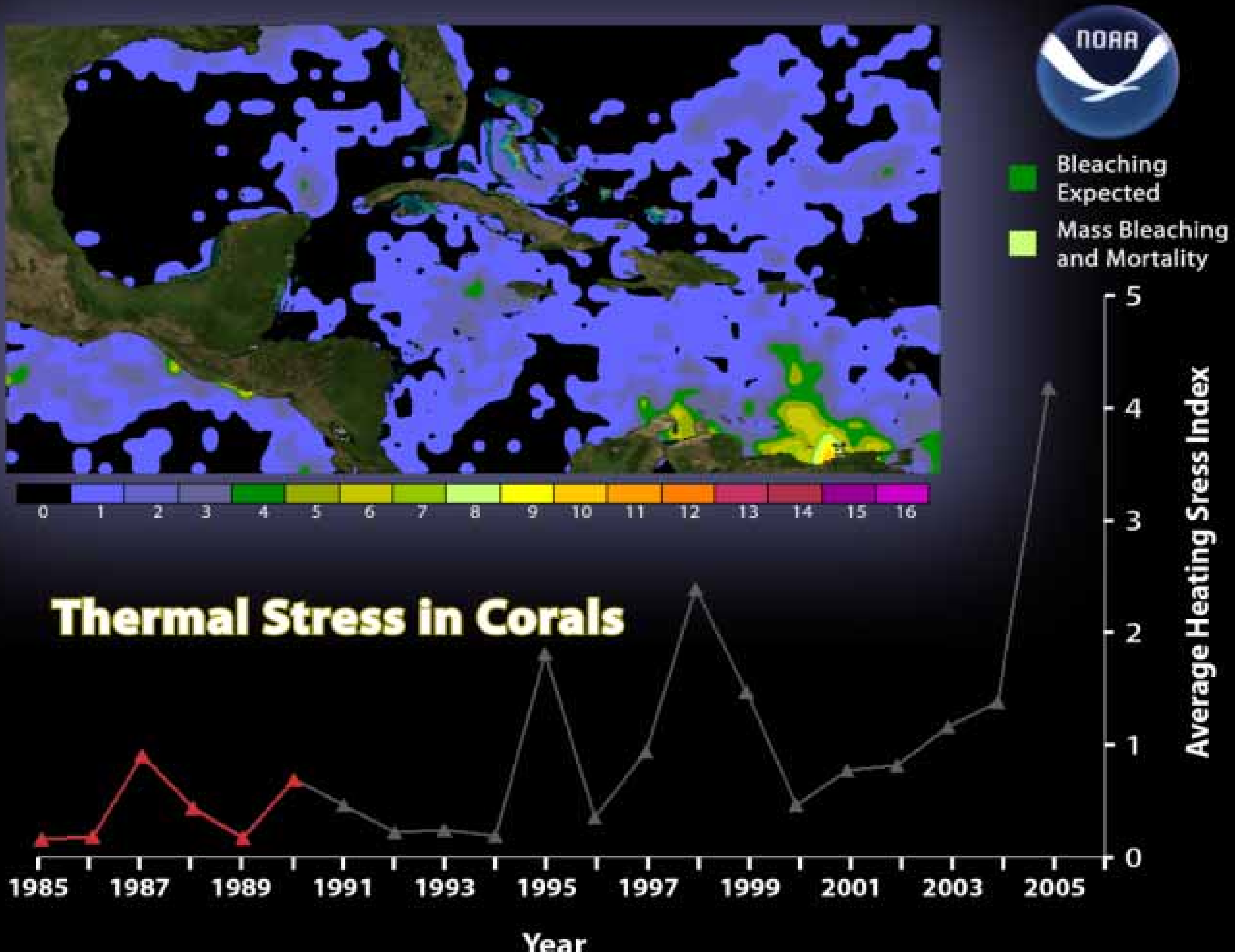
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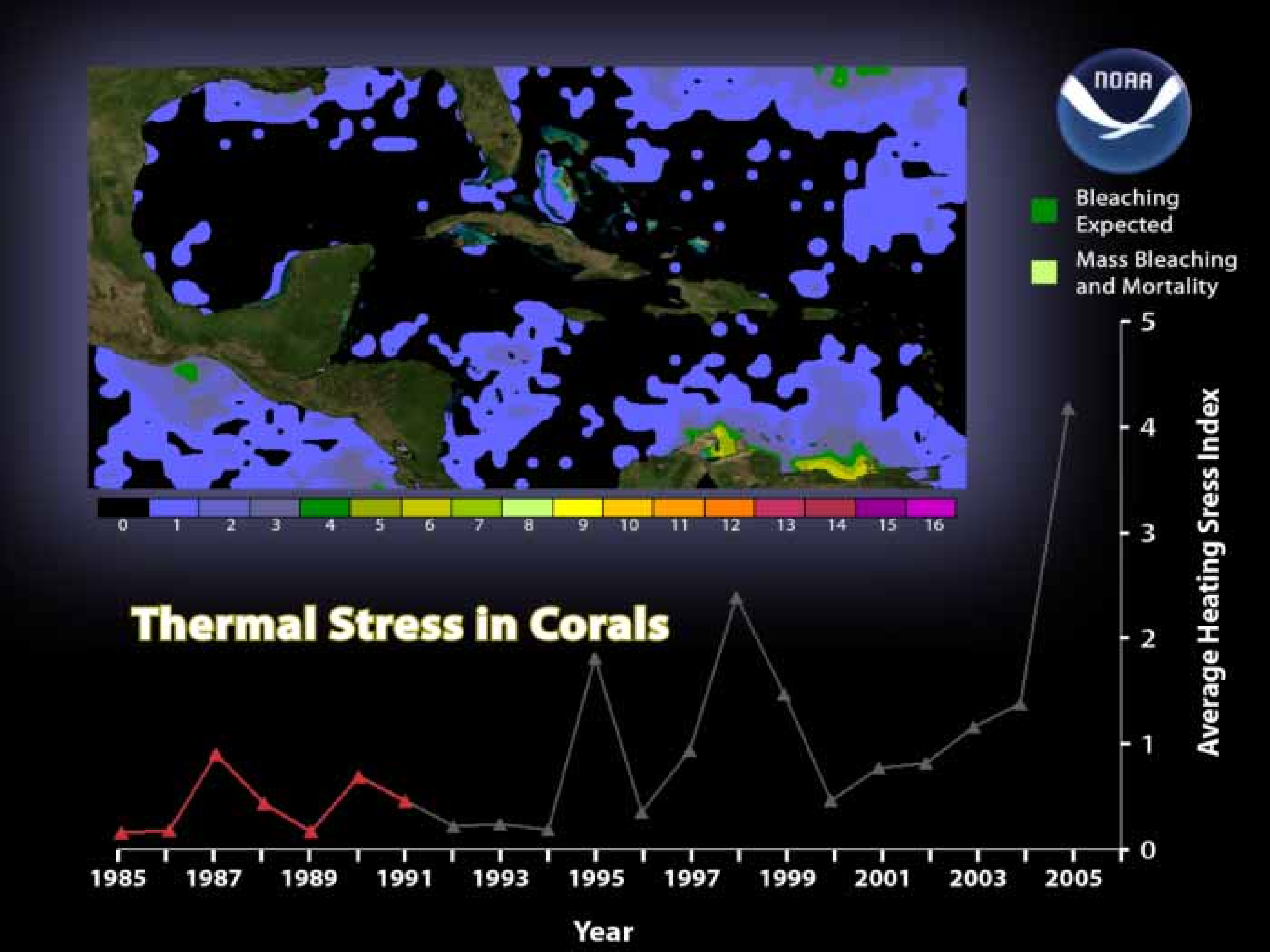

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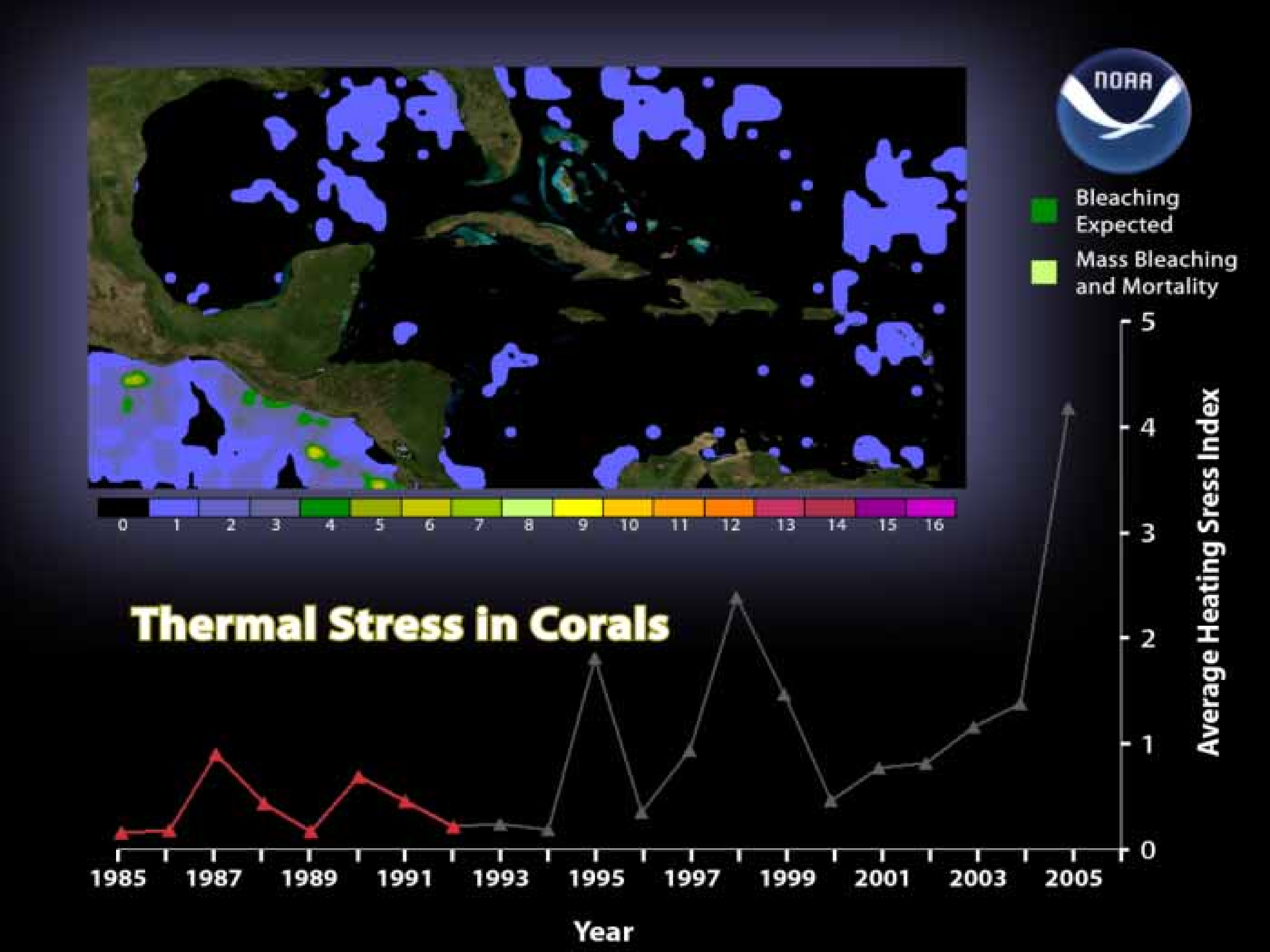

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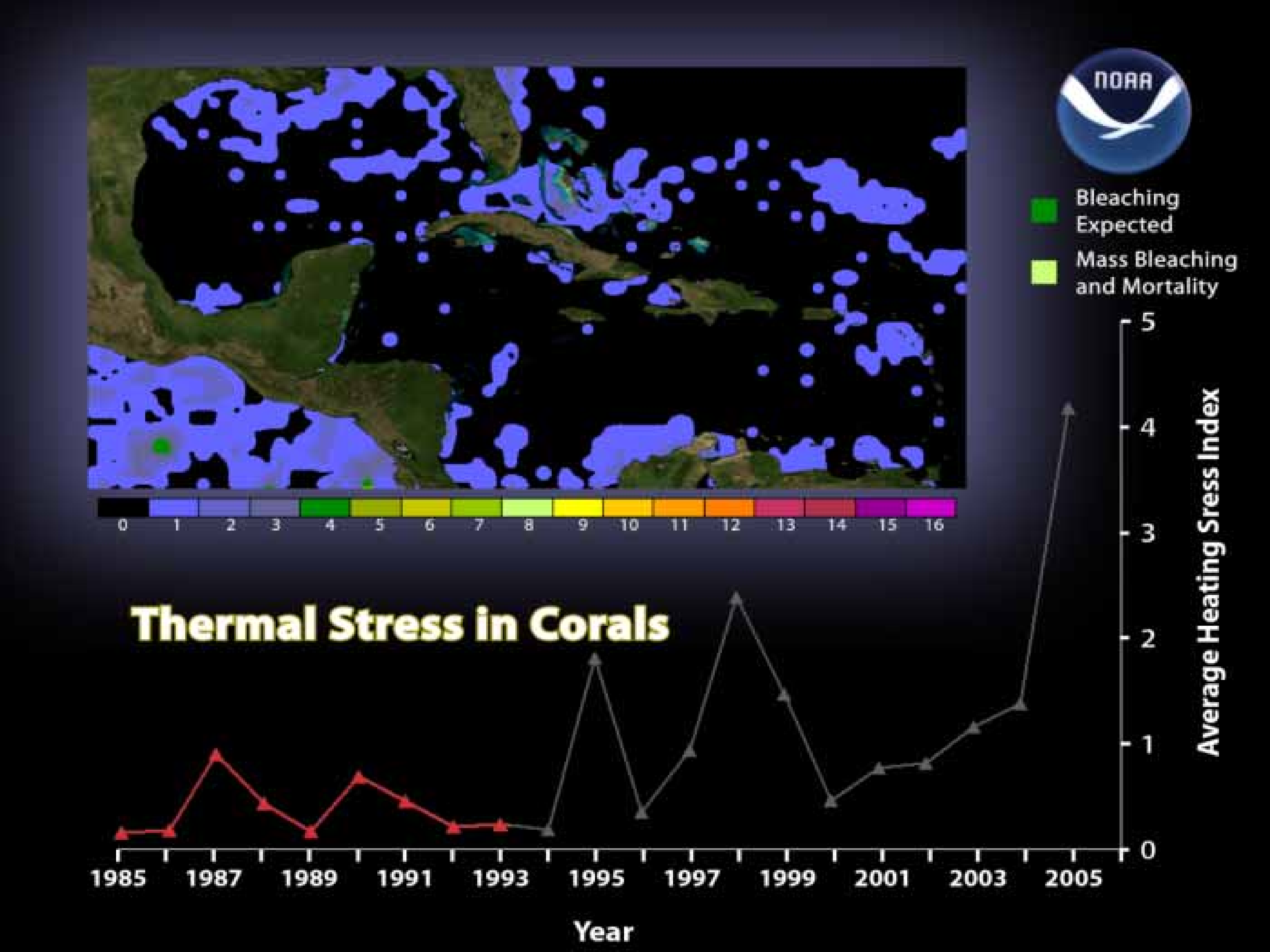

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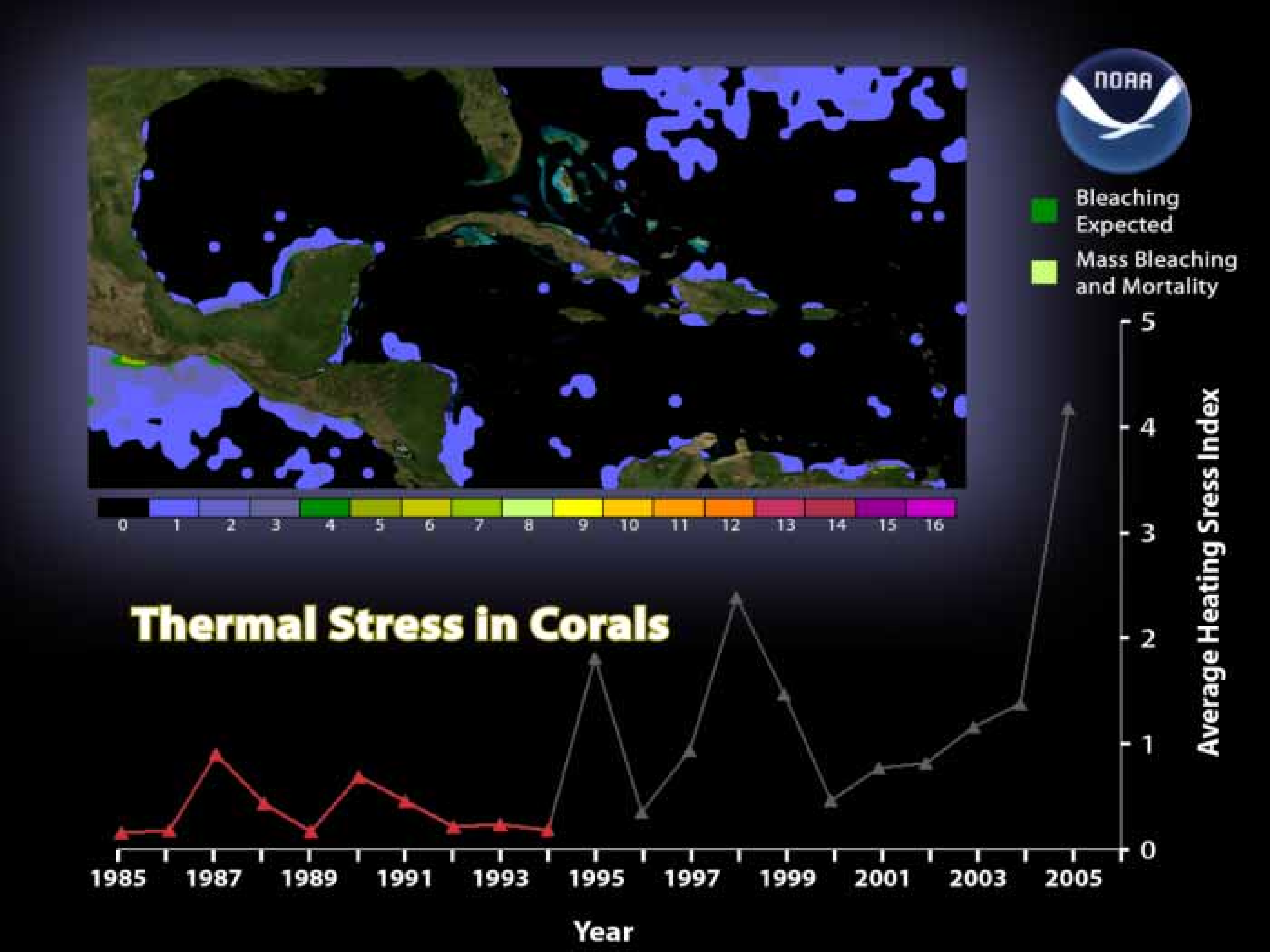

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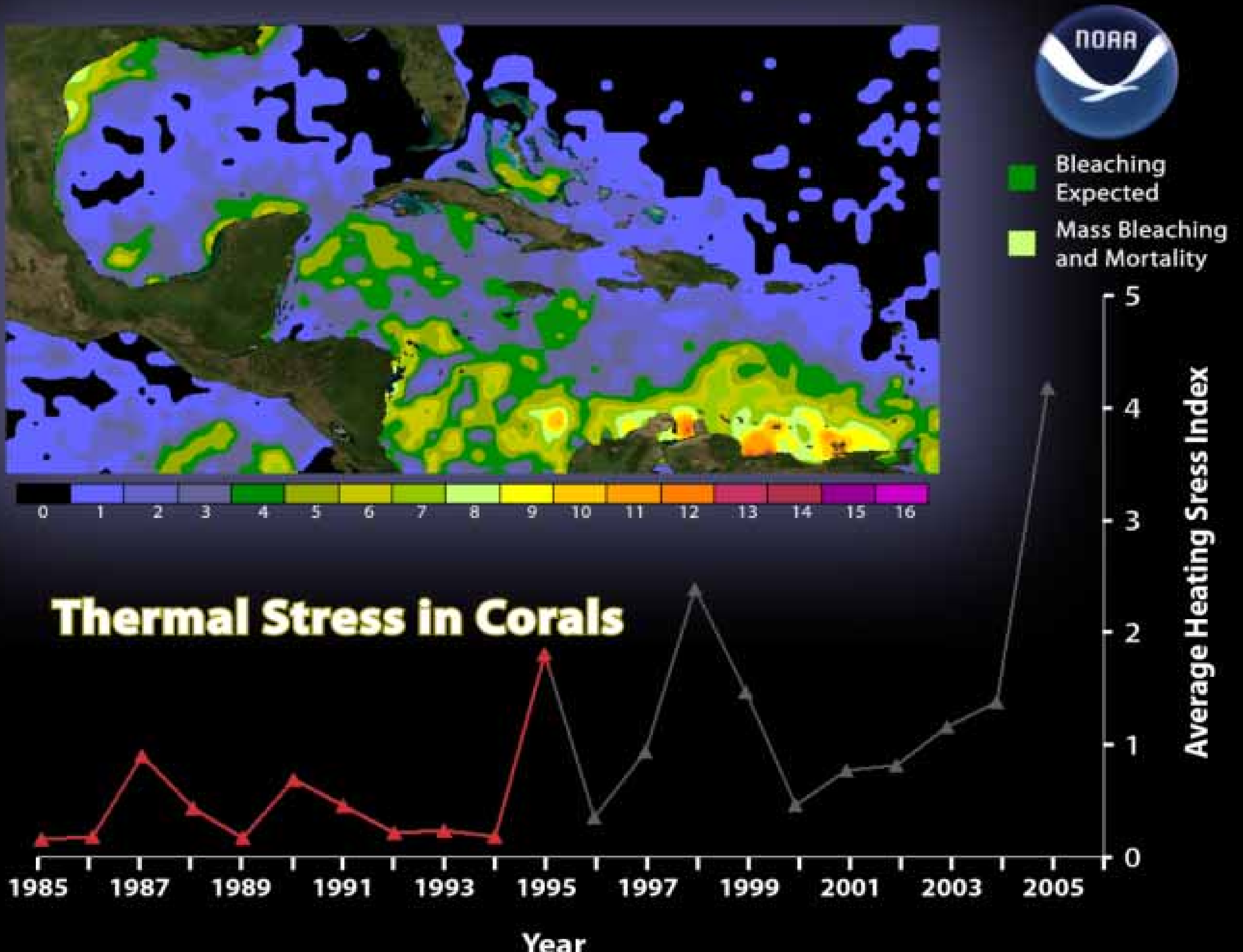
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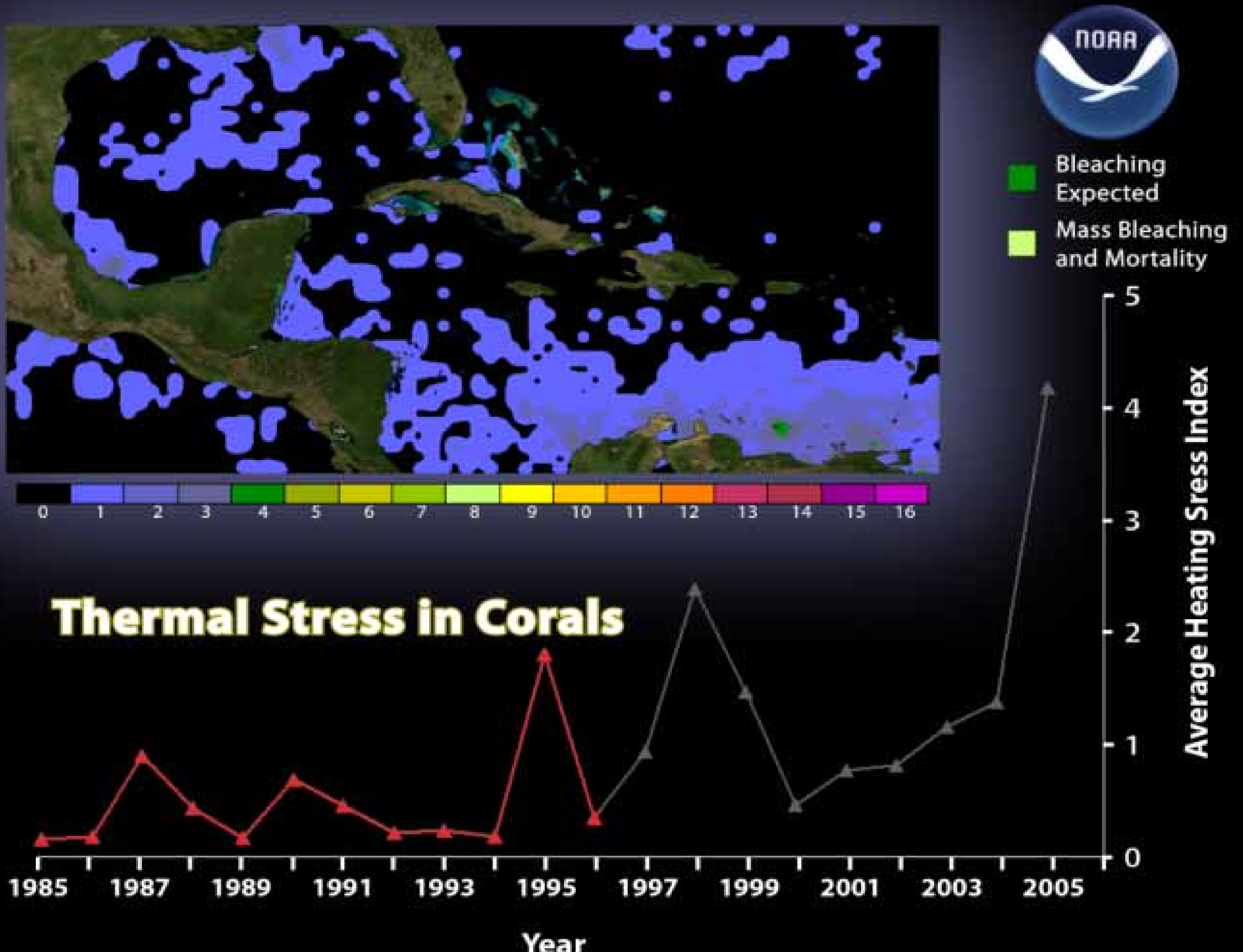

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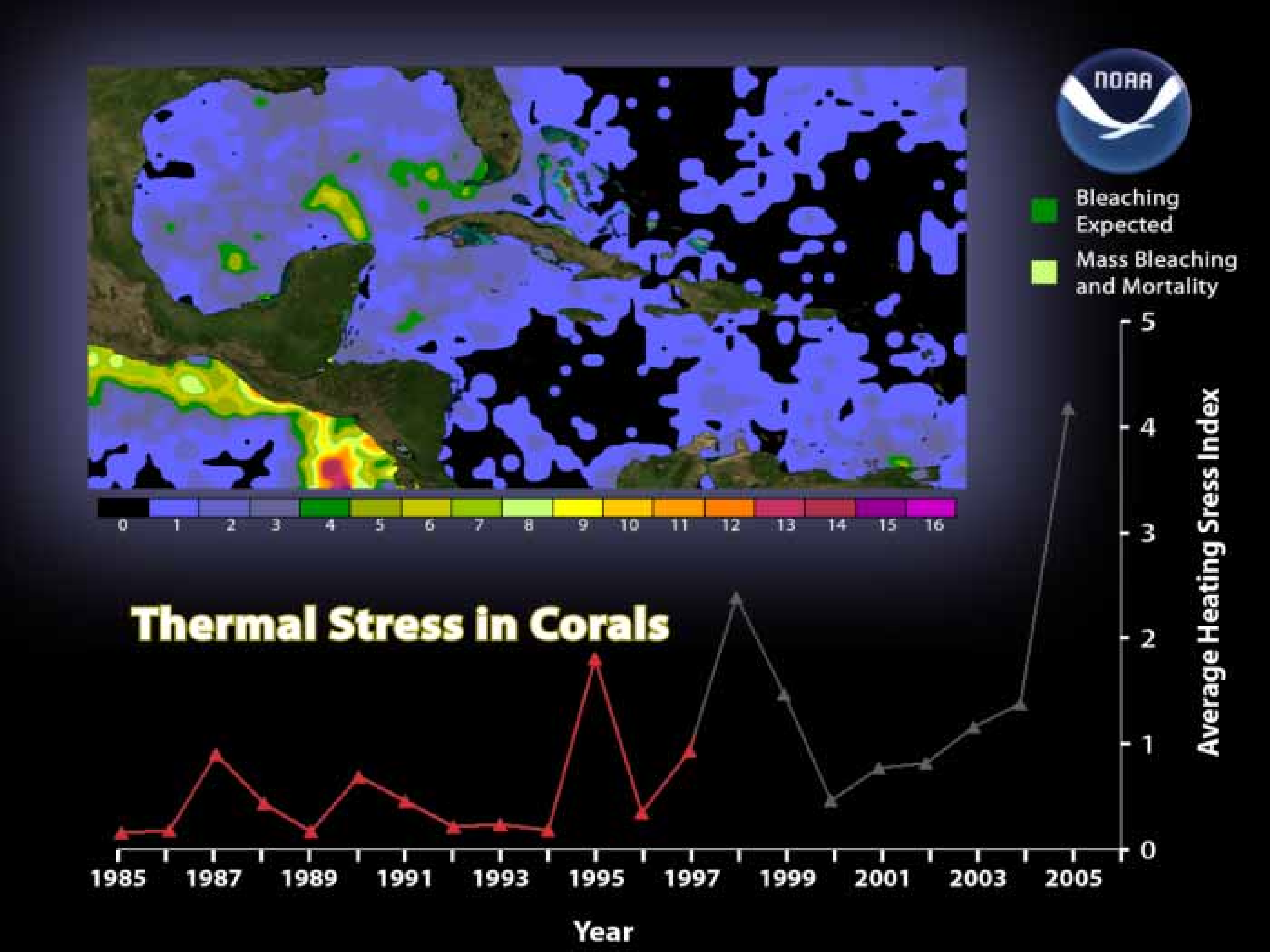
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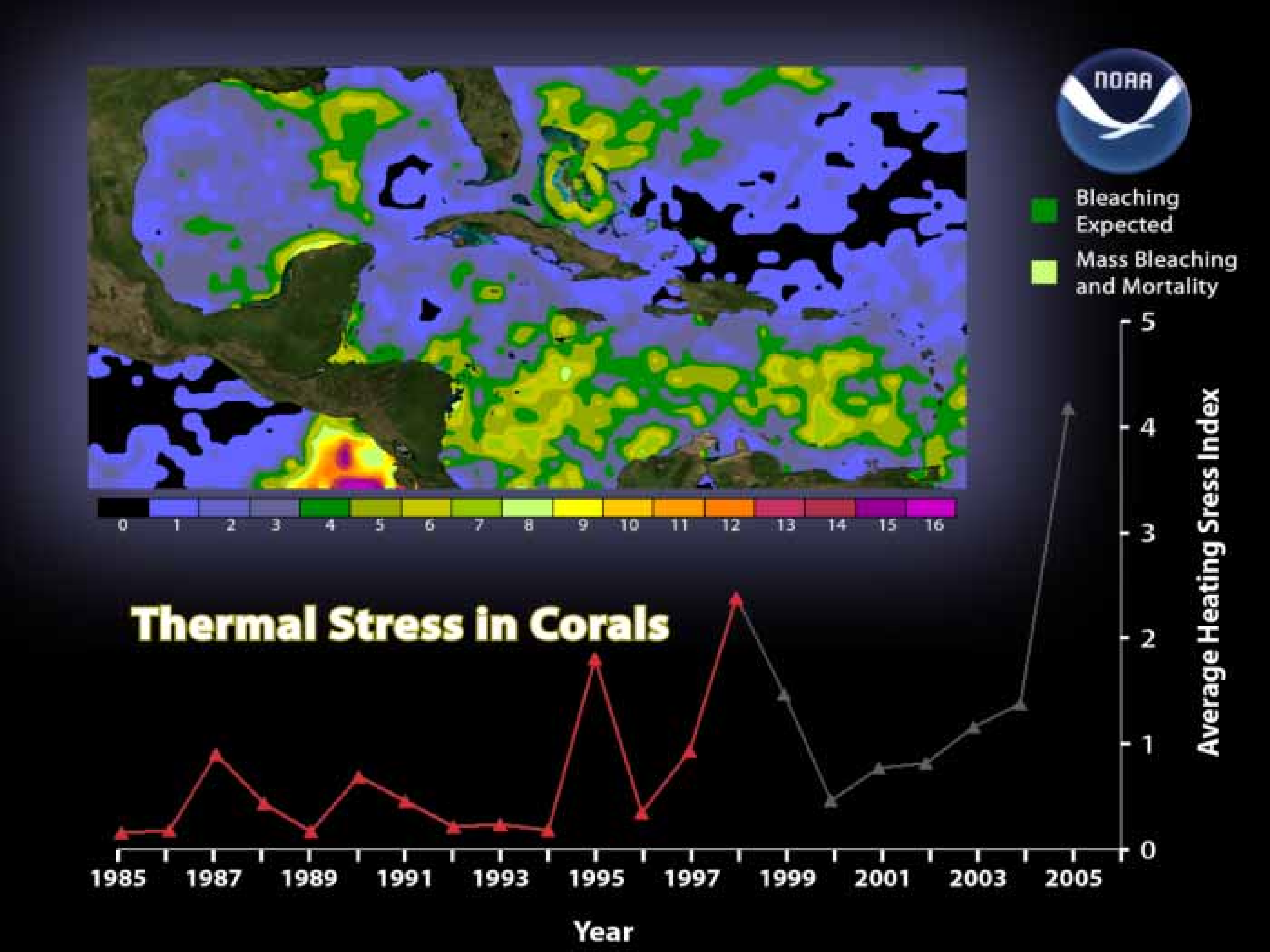
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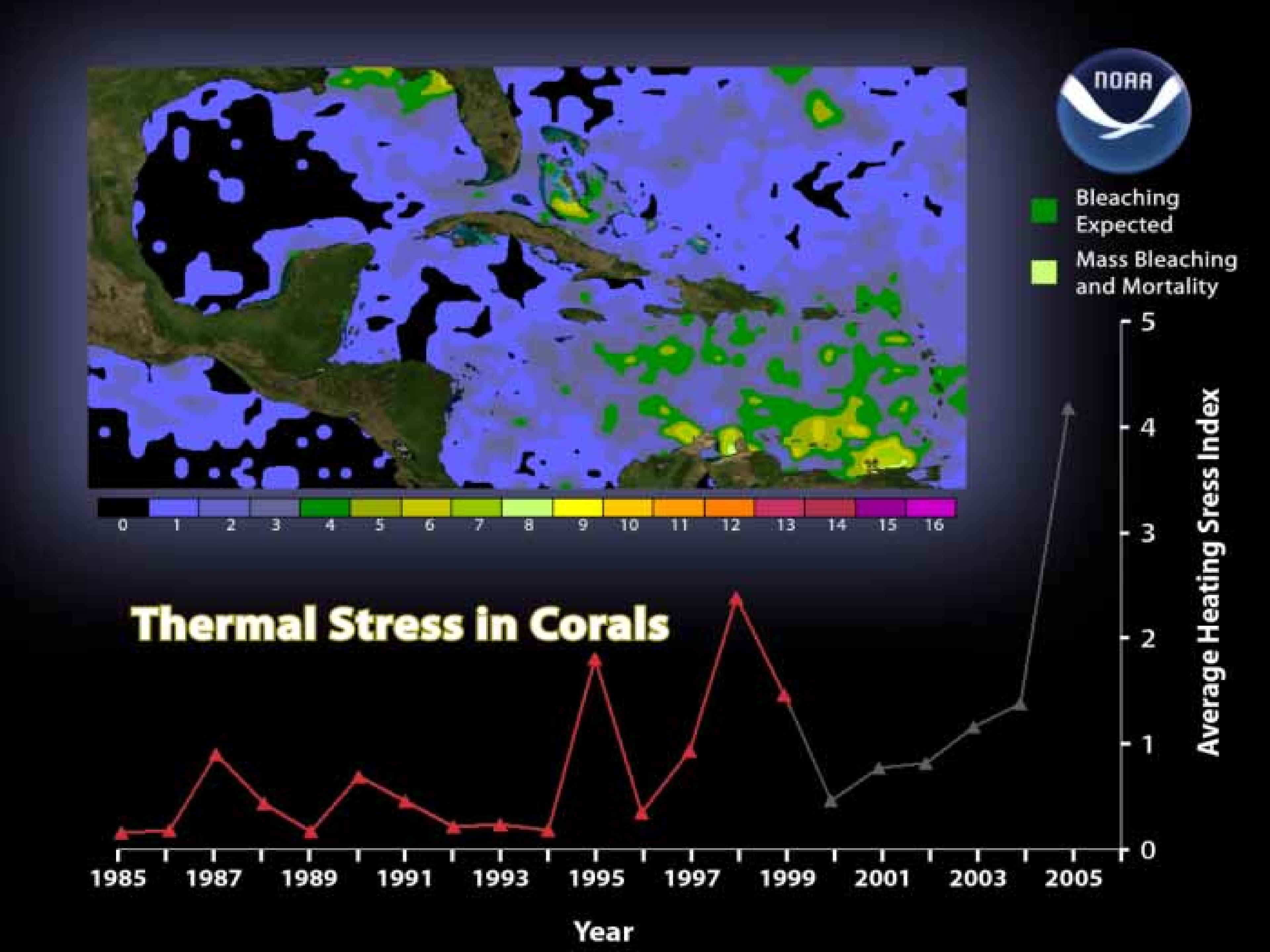
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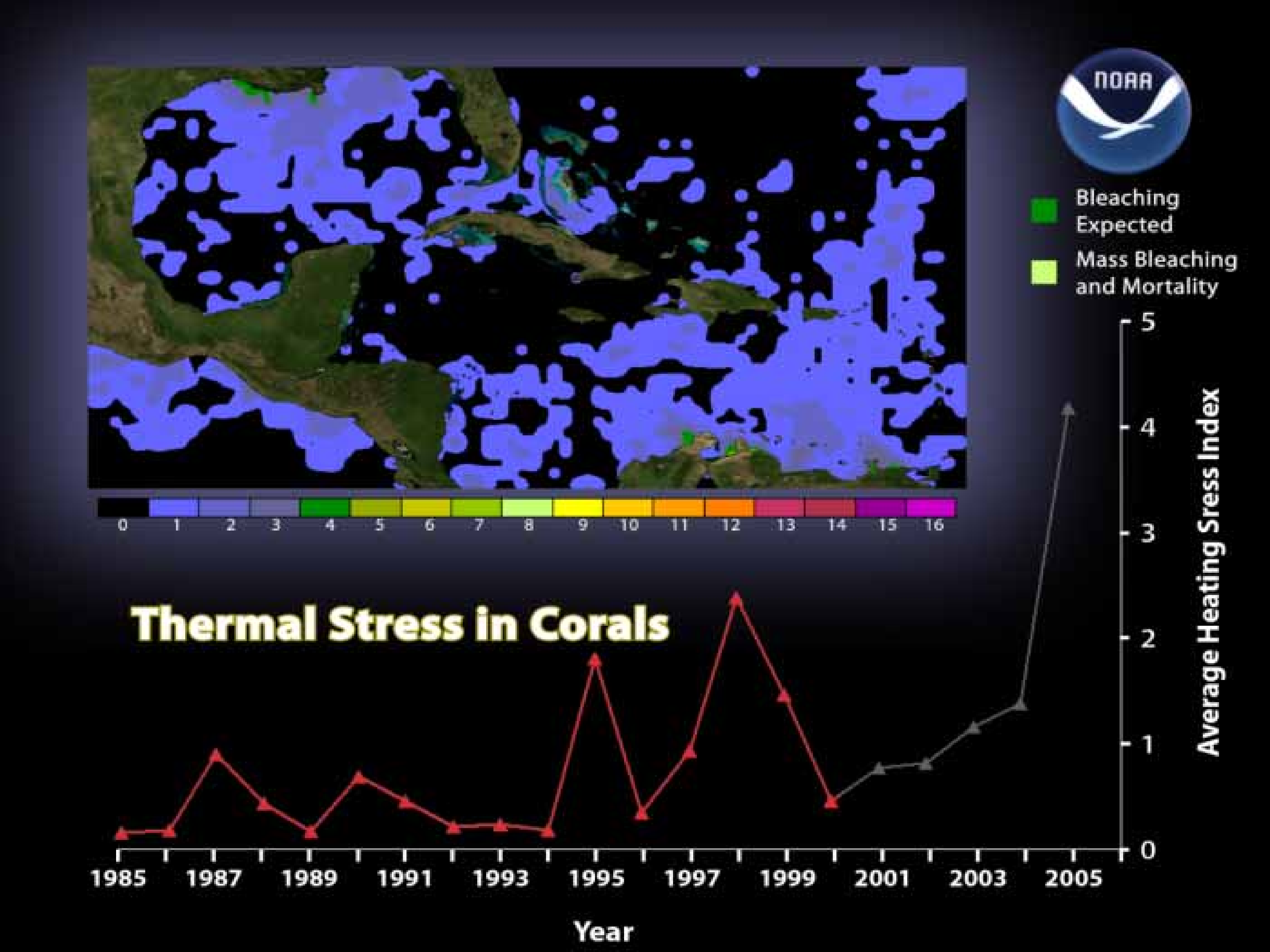
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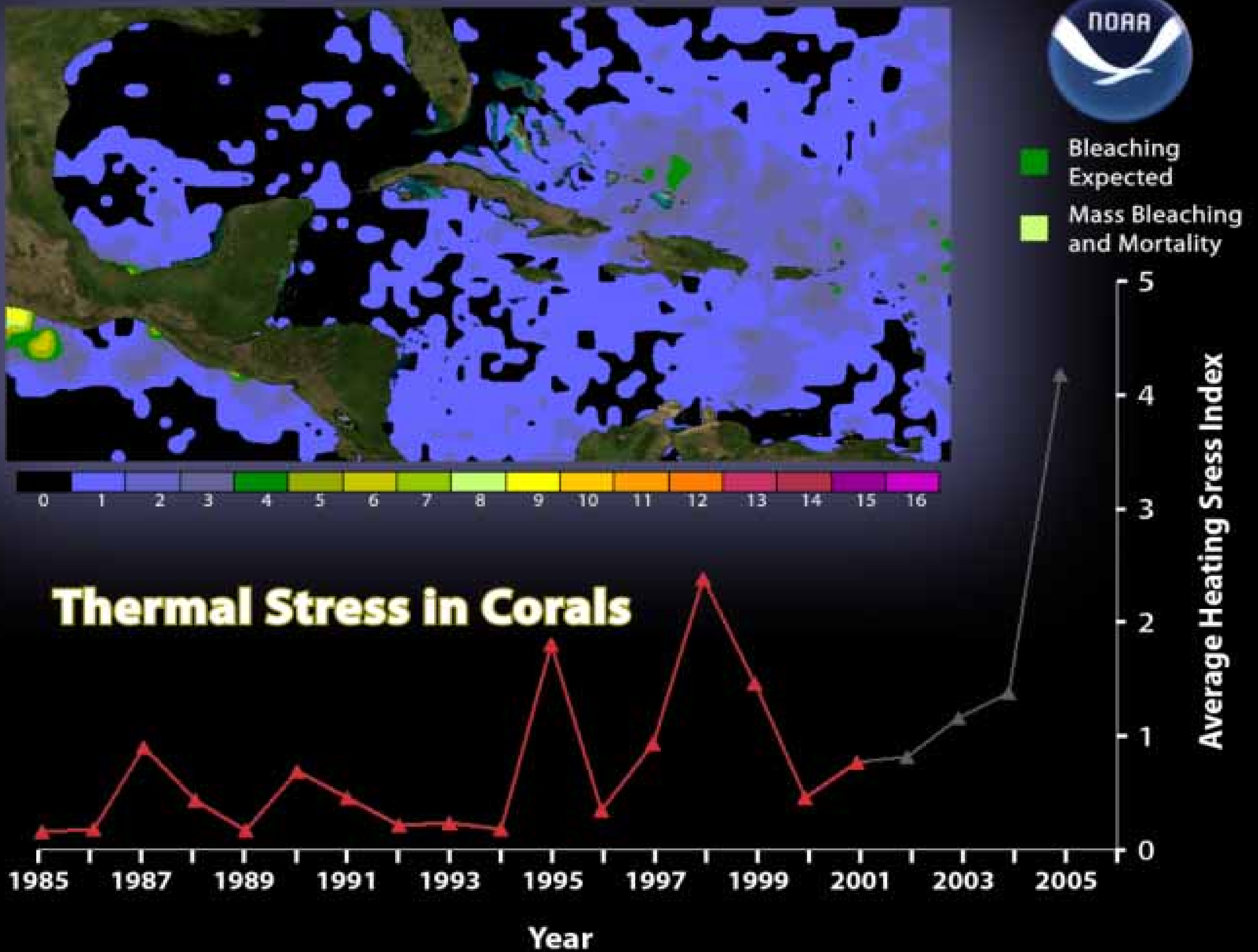

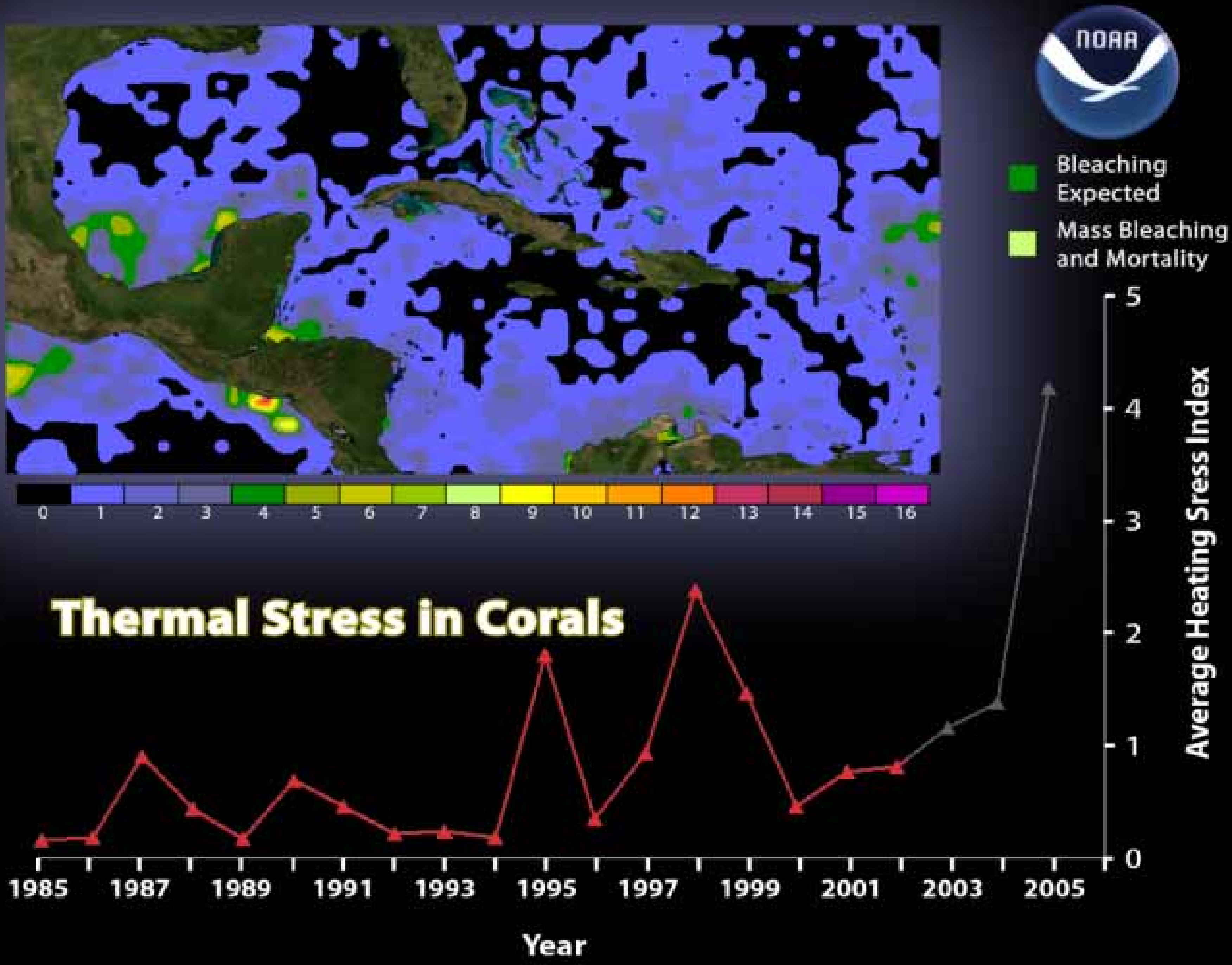
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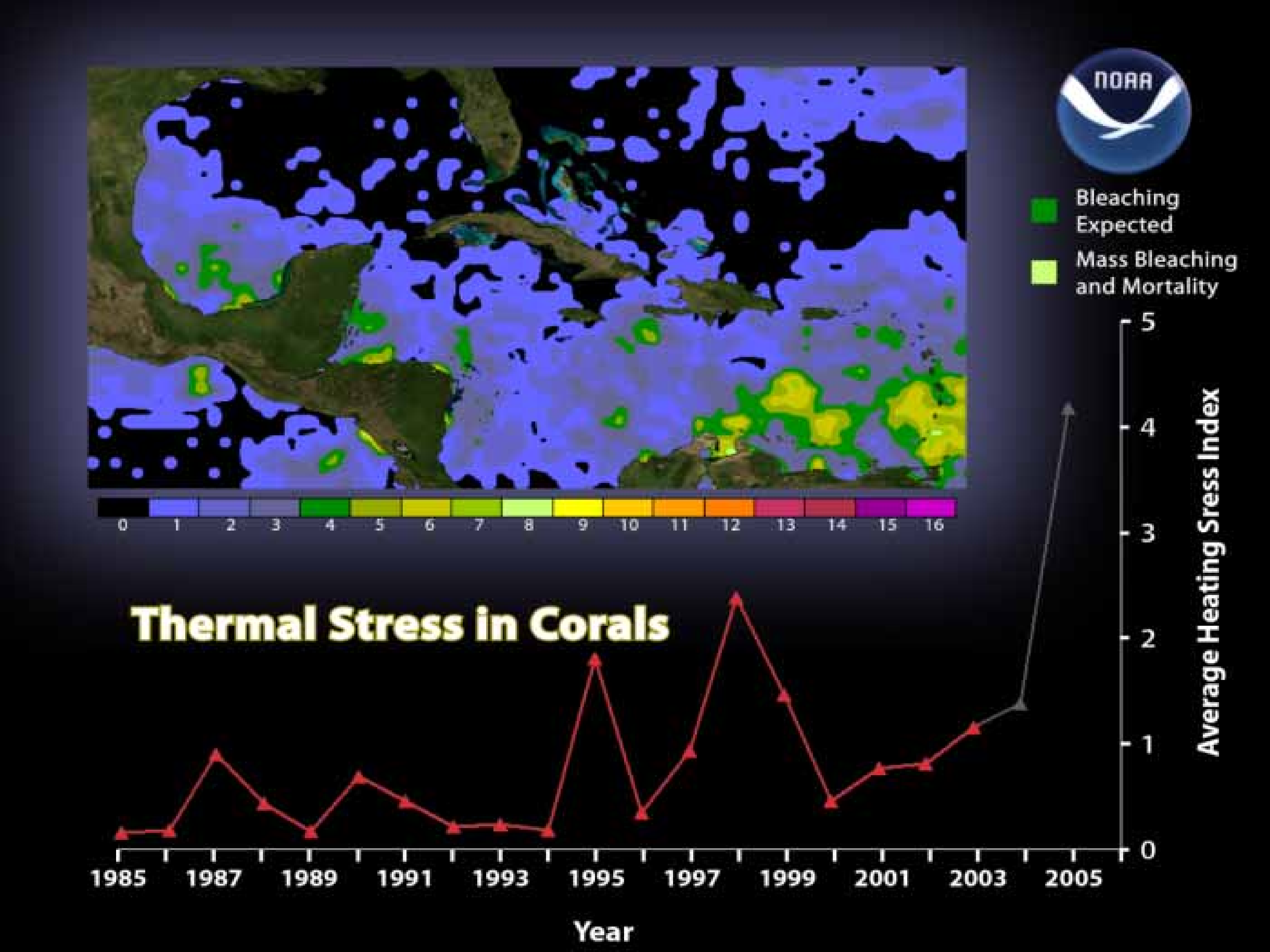
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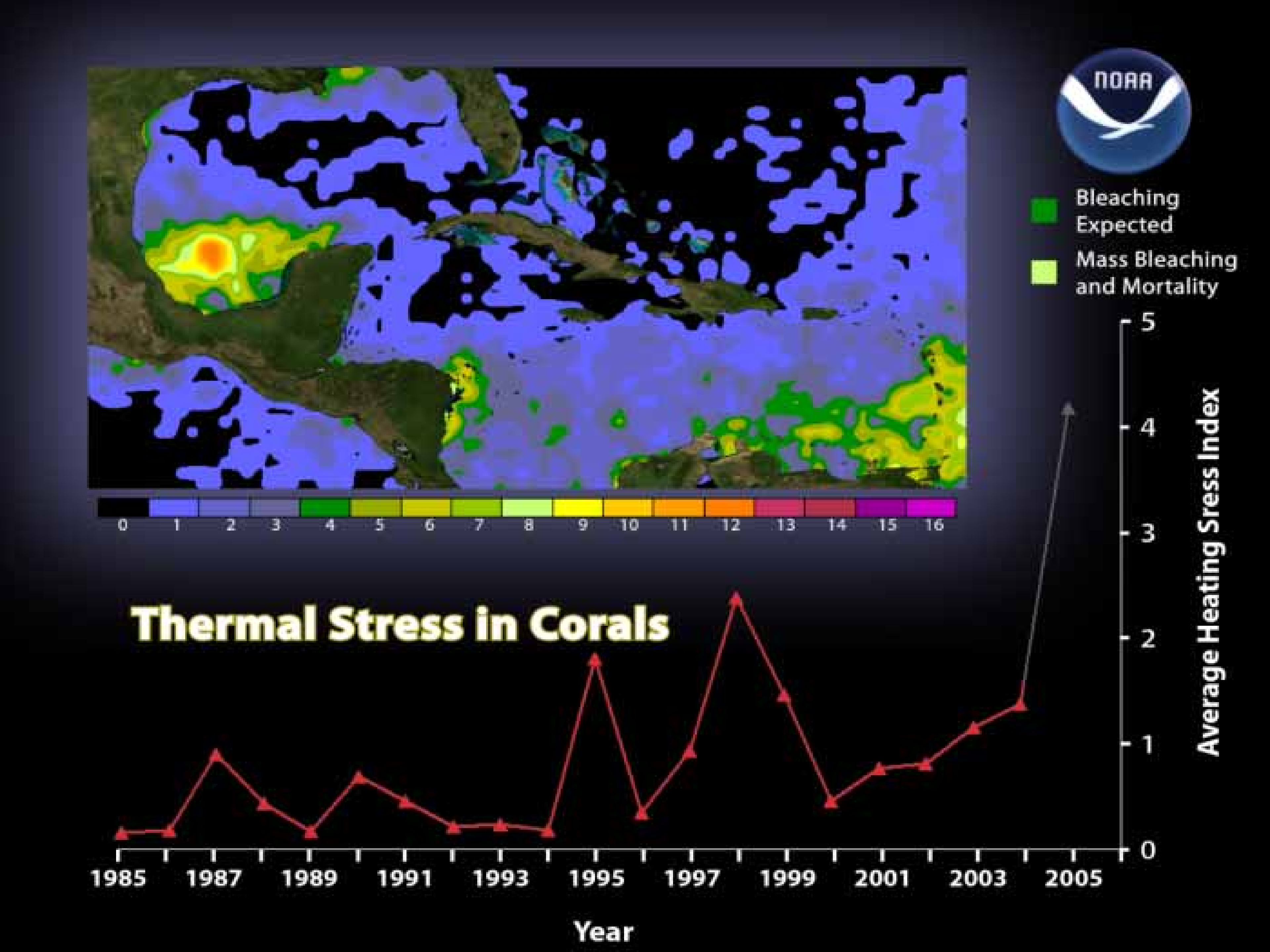

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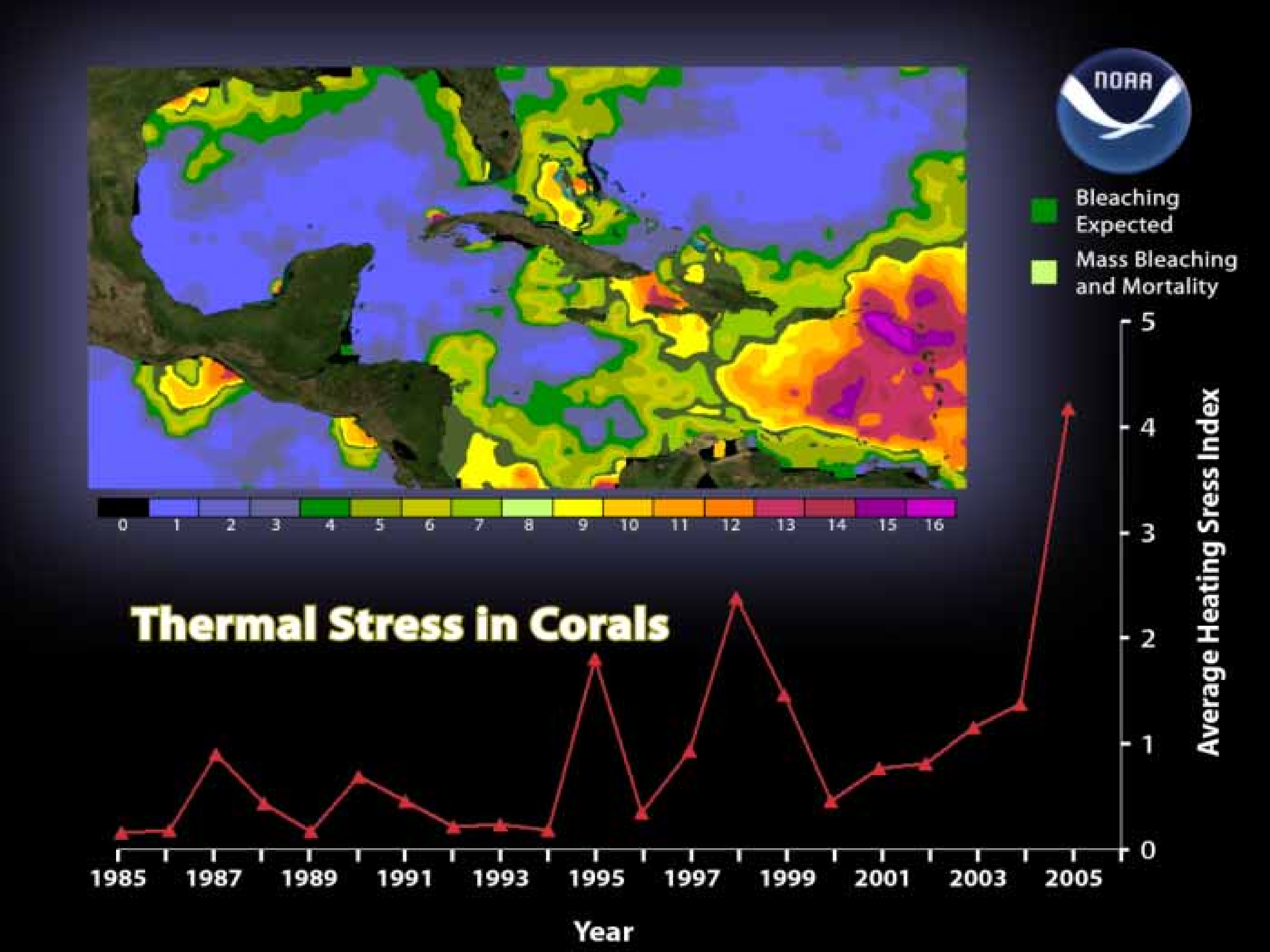

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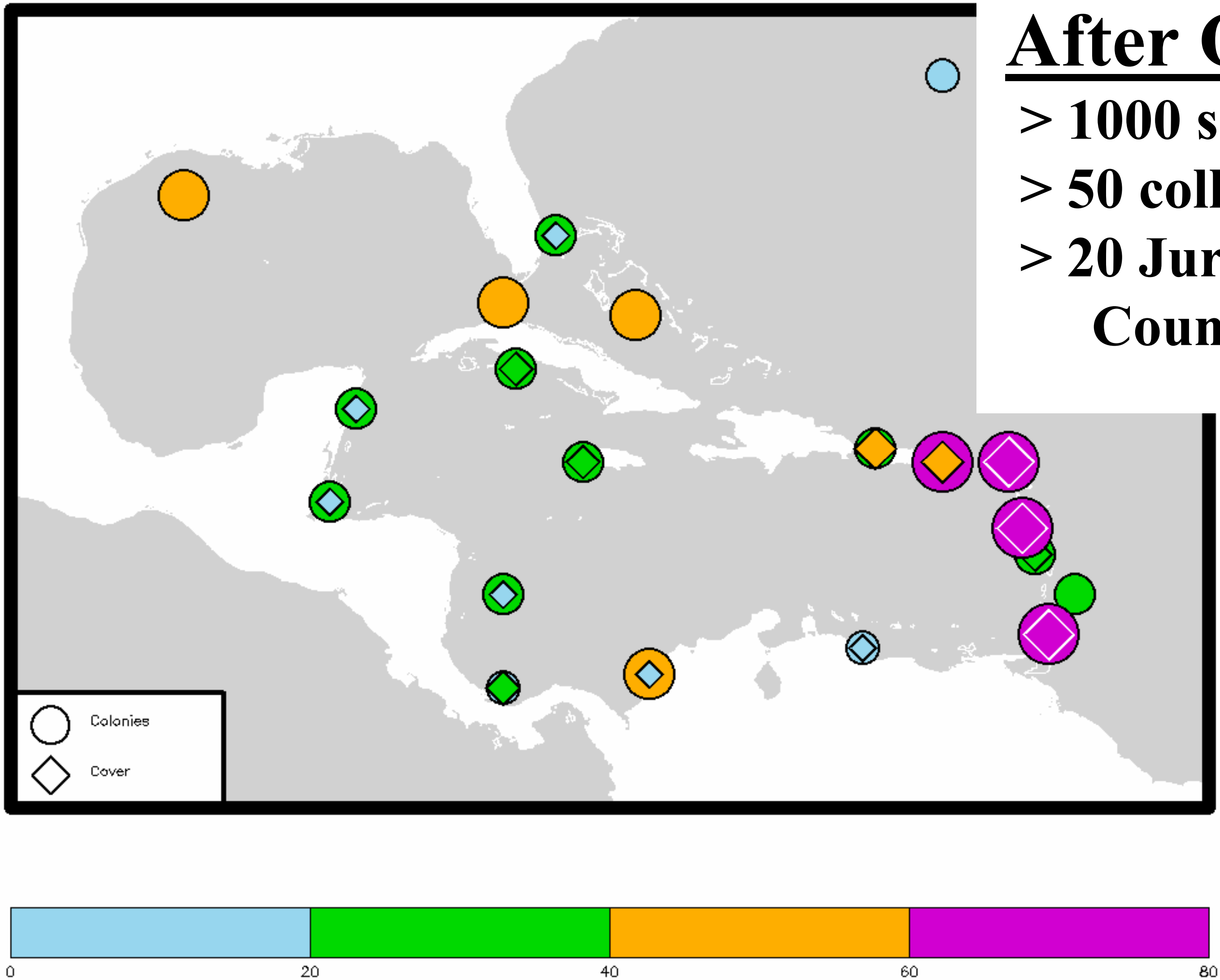
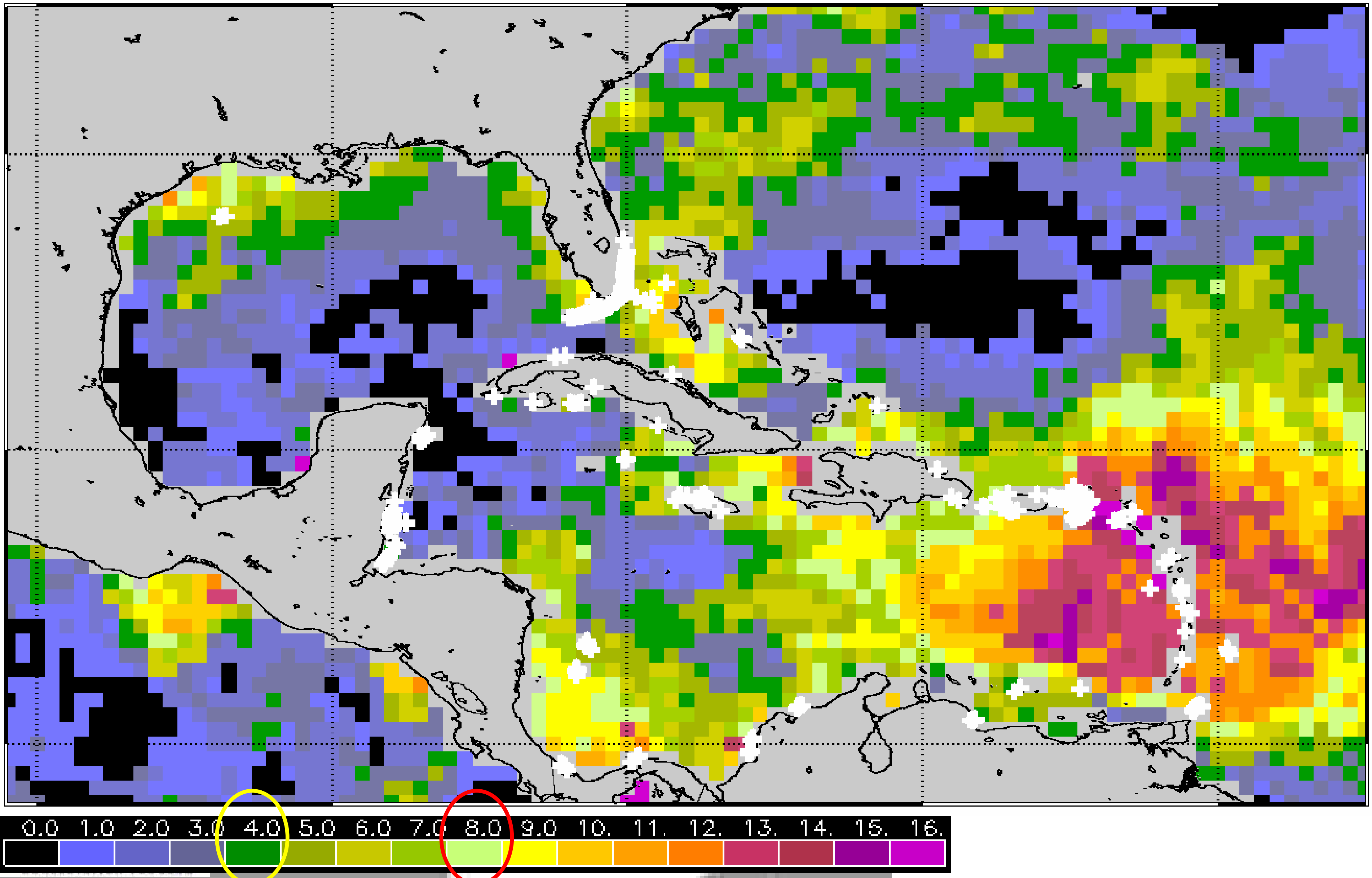
Percent of Coral Colonies Bleached



After QC:

> 1000 surveys
> 50 collaborators
> 20 Jurisdictions
Countries or States

Bleaching & Thermal Stress



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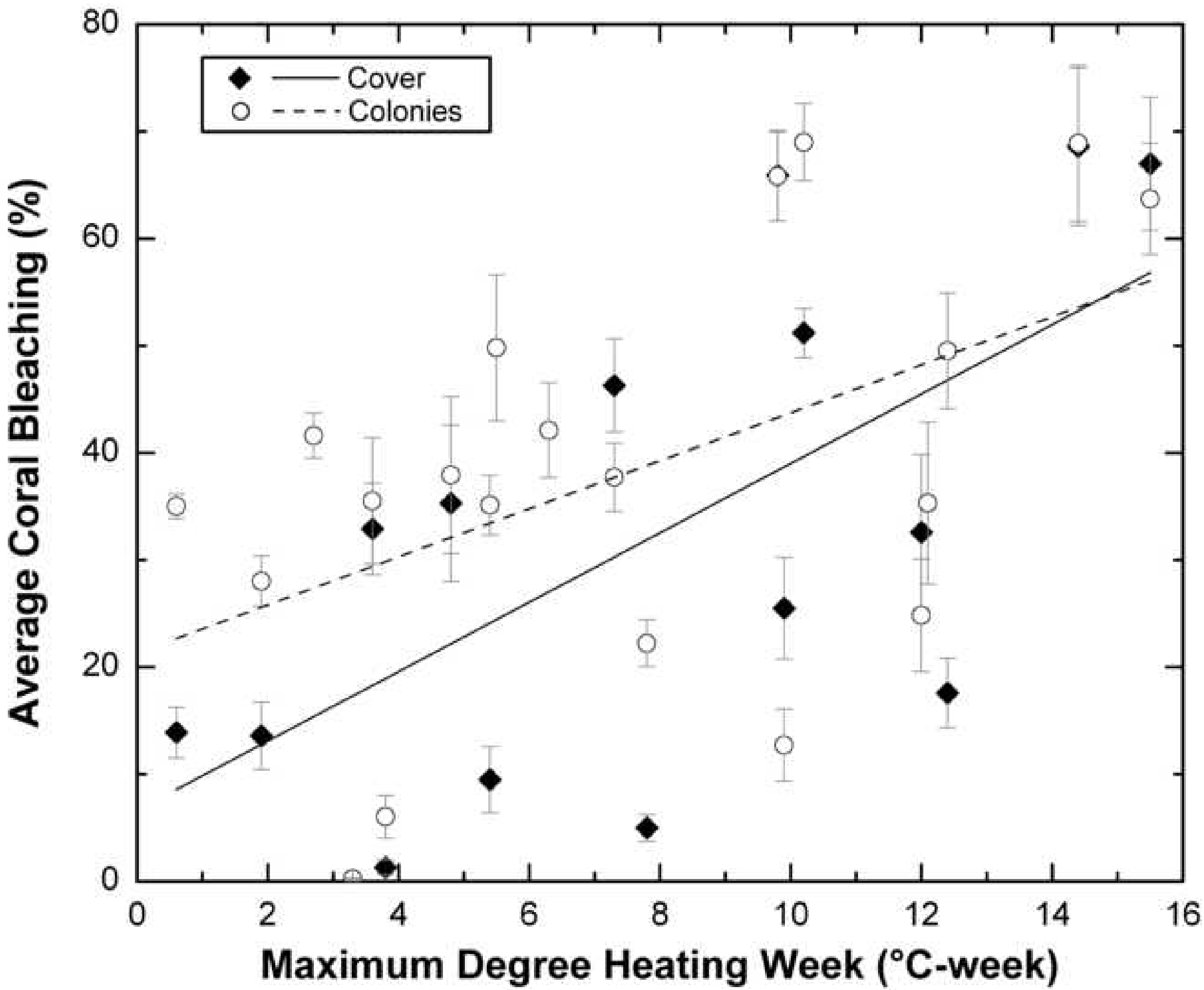
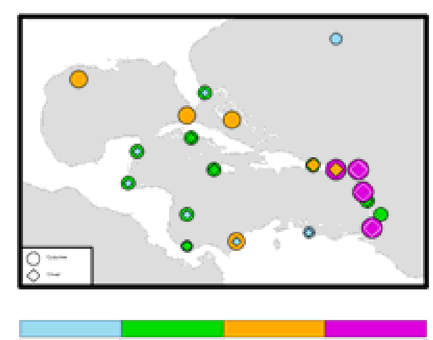




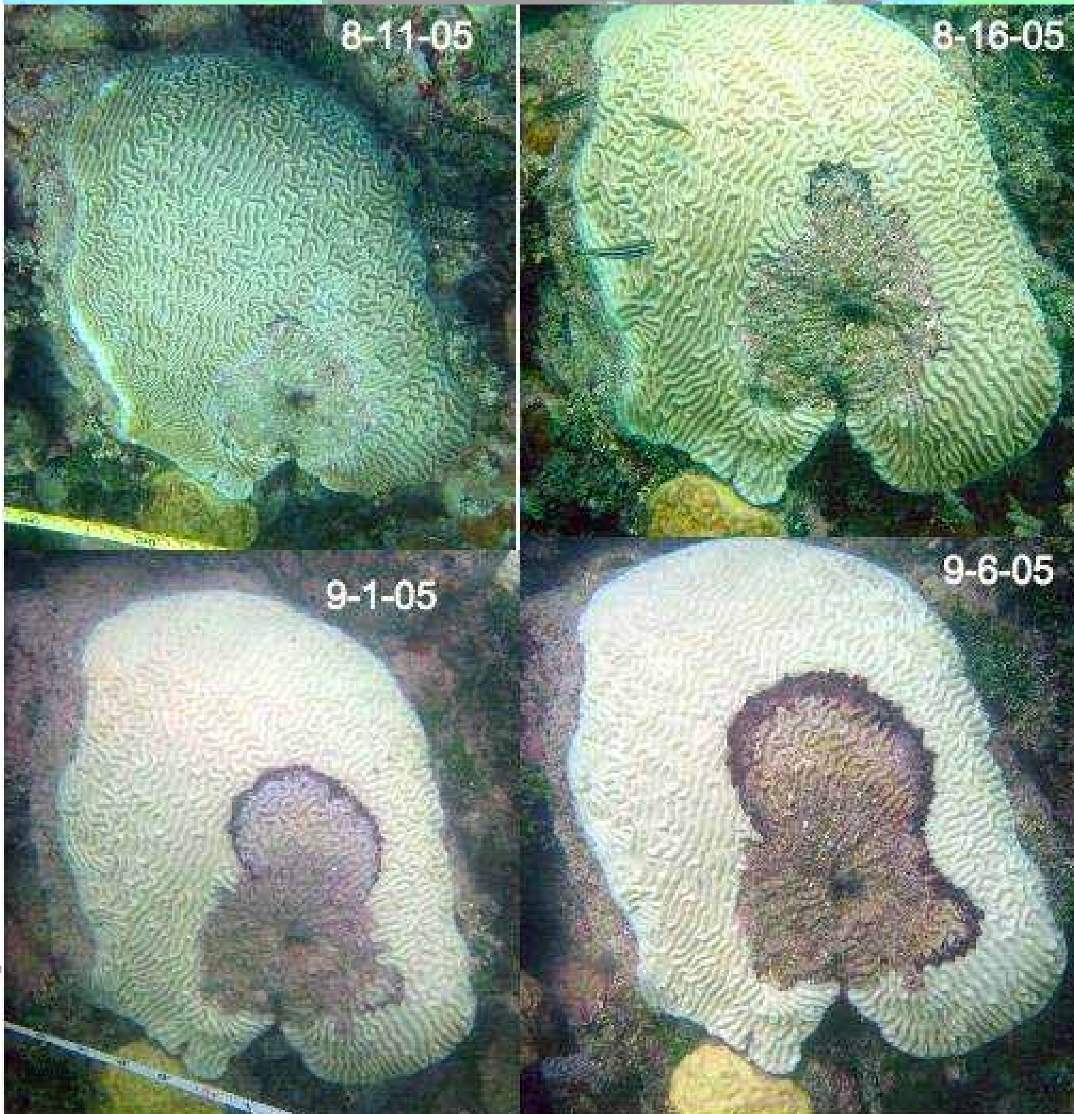
Thermal Stress Increases Disease

- **Many bleached colonies have become diseased**

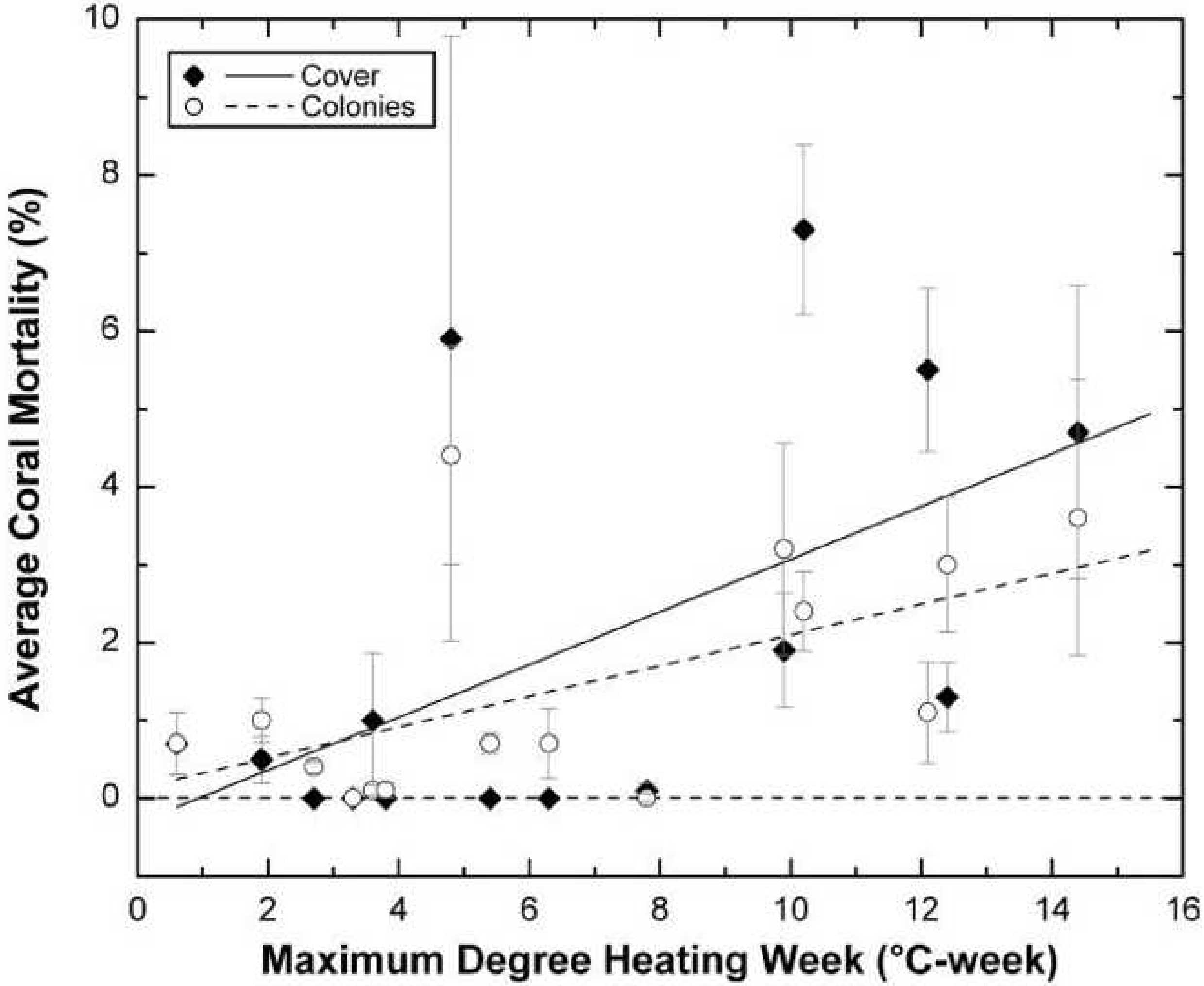
- **Some diseases are rapid and devastating**

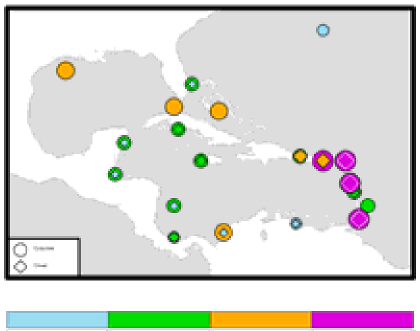
Inshore patch reefs
Middle Florida Keys

Marilyn E. Brandt
University of Miami

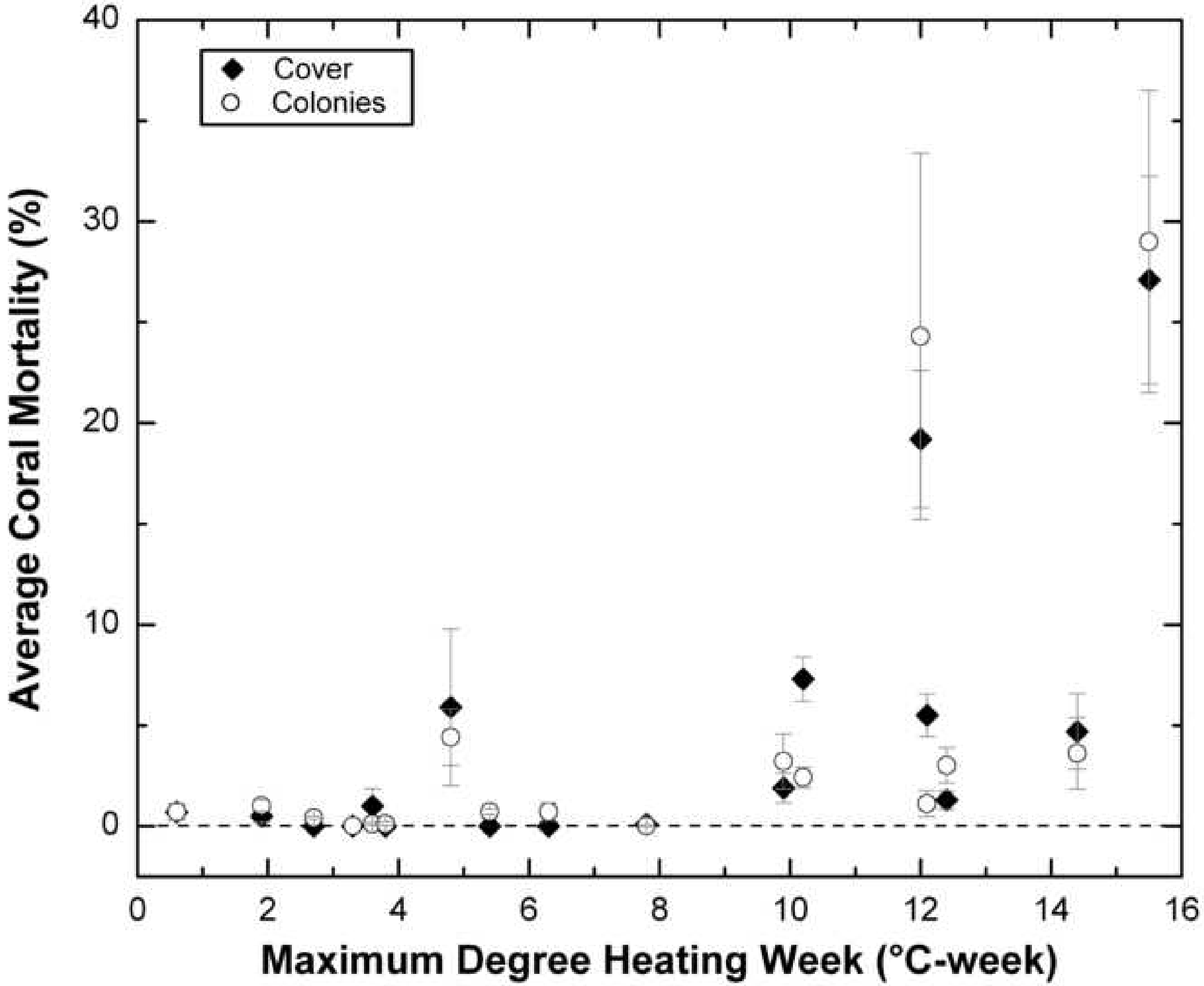


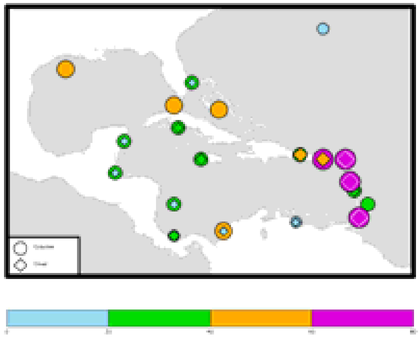
Immediate Mortality (by Jan. 2006)





Long-Term (1 year) Mortality





Virgin Islands N.P. Coral Bleaching Surveys

S. Fore Reef, BUIS

96% coral cover bleached
42% coral cover dead

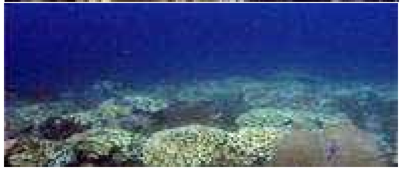
Tektite, VIIS

90% coral cover bleached
54% coral cover dead

Haulover, VIIS

96% coral cover bleached
45% coral cover dead

Mennebeck, VIIS

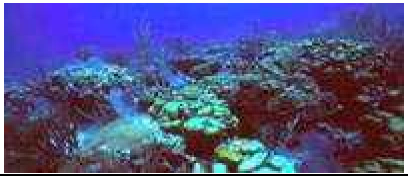


94% coral cover bleached
49% coral cover dead

Yawzi, VIIS

71% coral cover bleached
39% coral cover dead

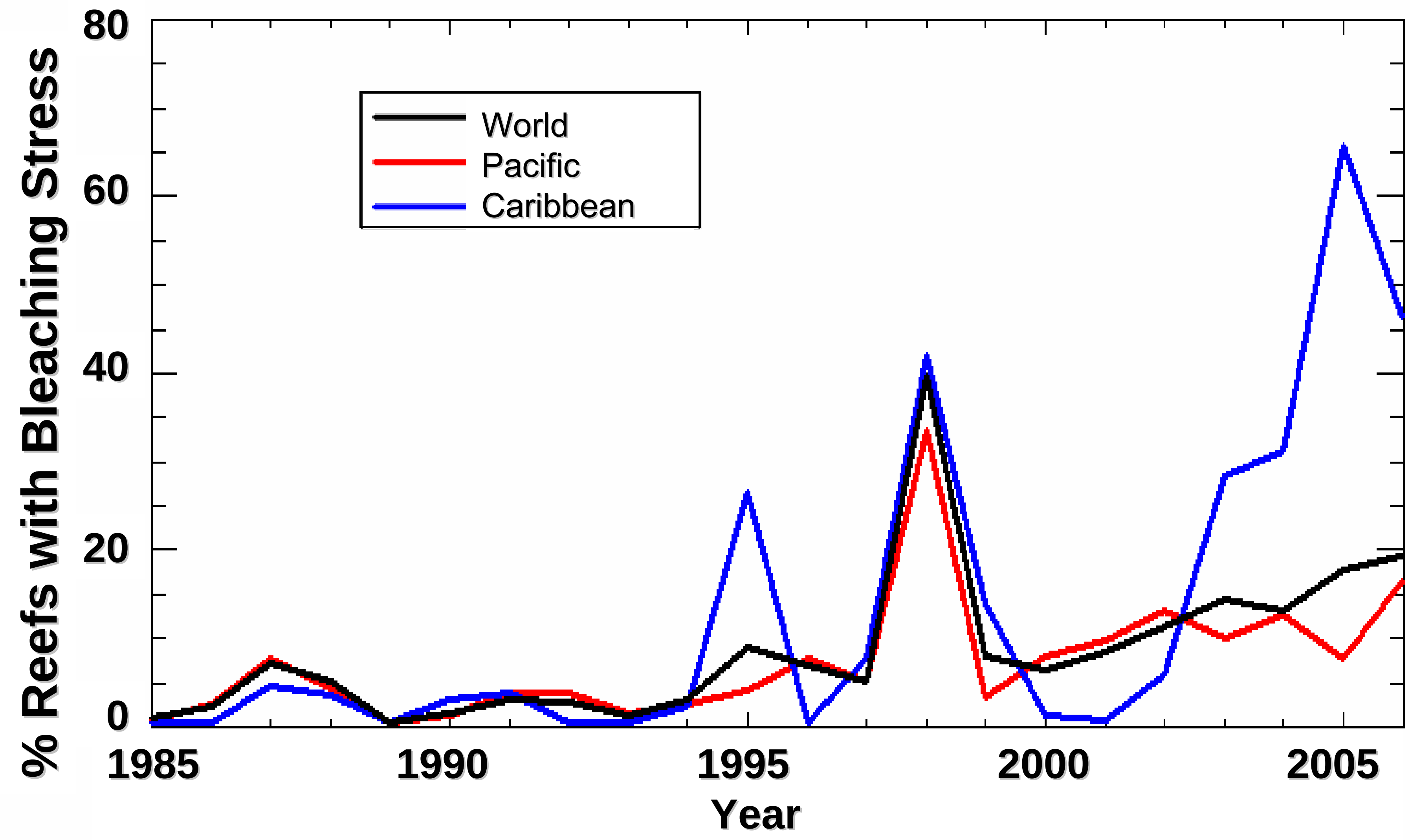
Newfound, STJ



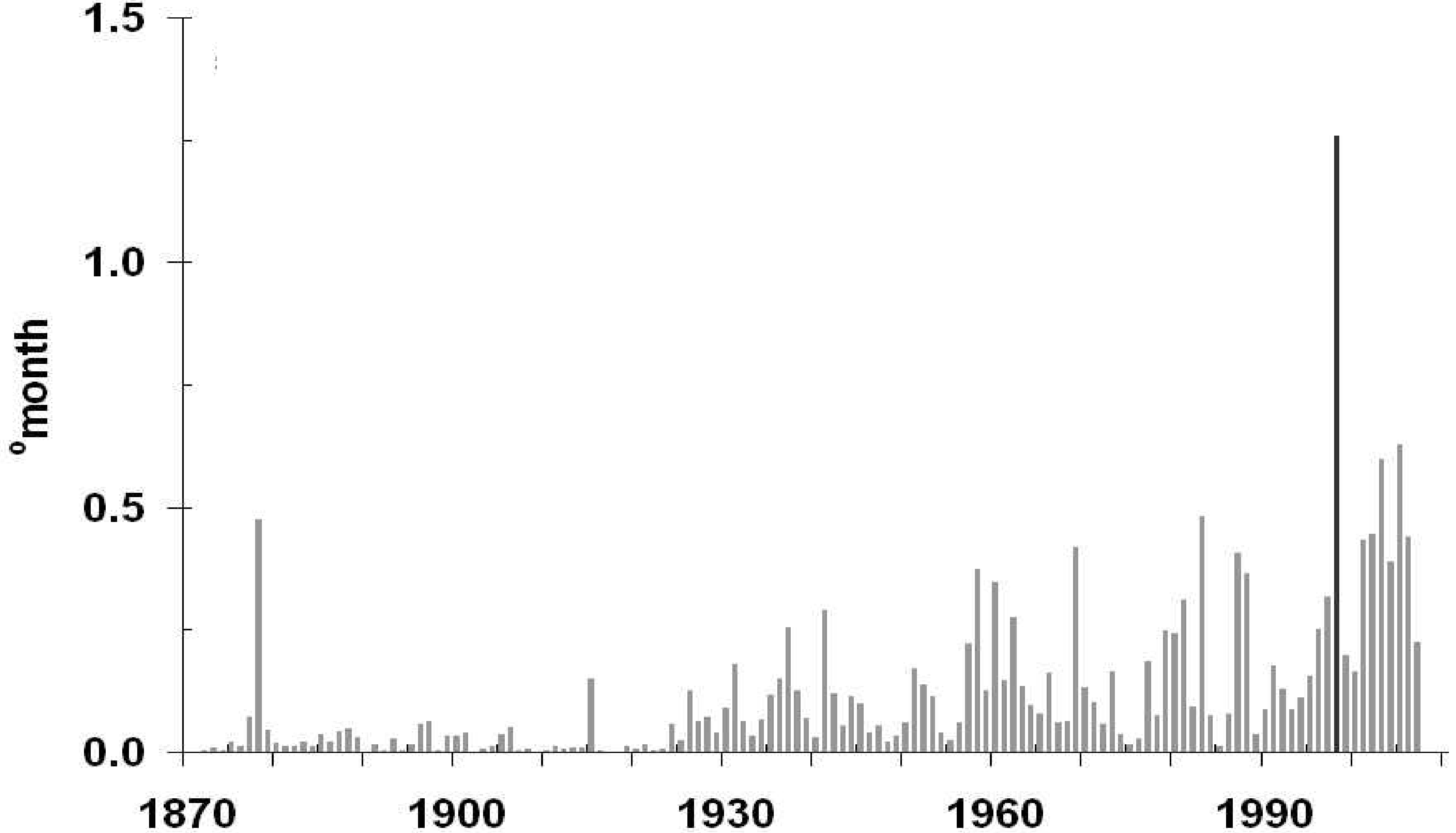
92% coral cover bleached
53% coral cover dead

J. Miller (unpublished)

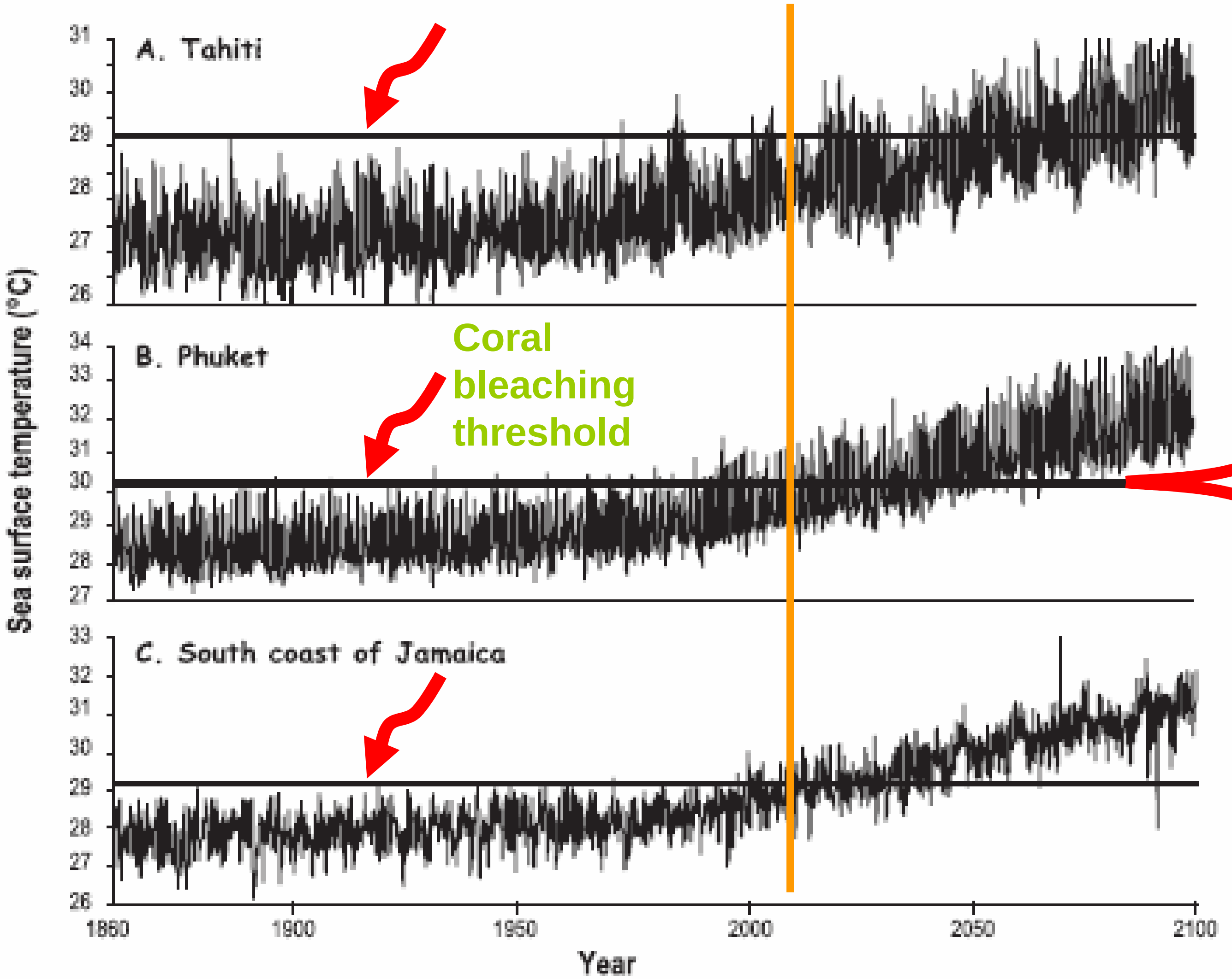
2005: Highest Thermal Stress Recorded?



135 Years of Thermal Stress Increase



Future Change



Photos by Ray Berkelmans, AIMS

Hoegh-Guldberg (1999)

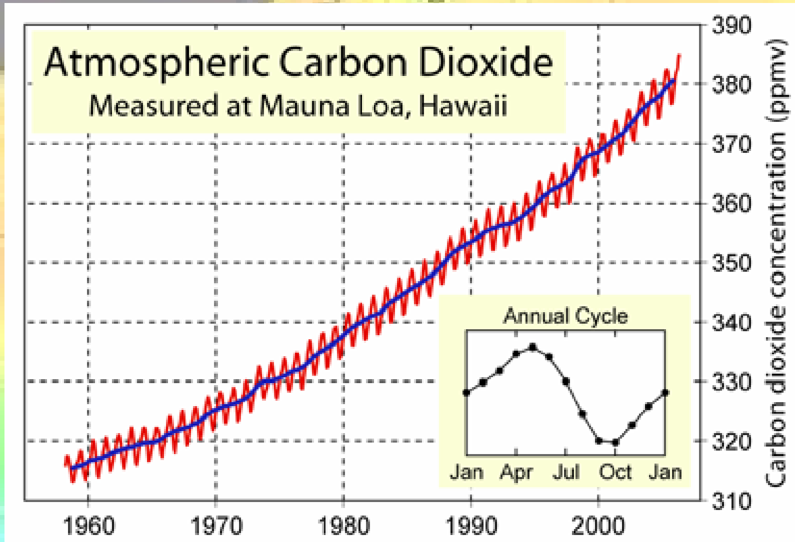
Wide Range of Coral Reef Threats

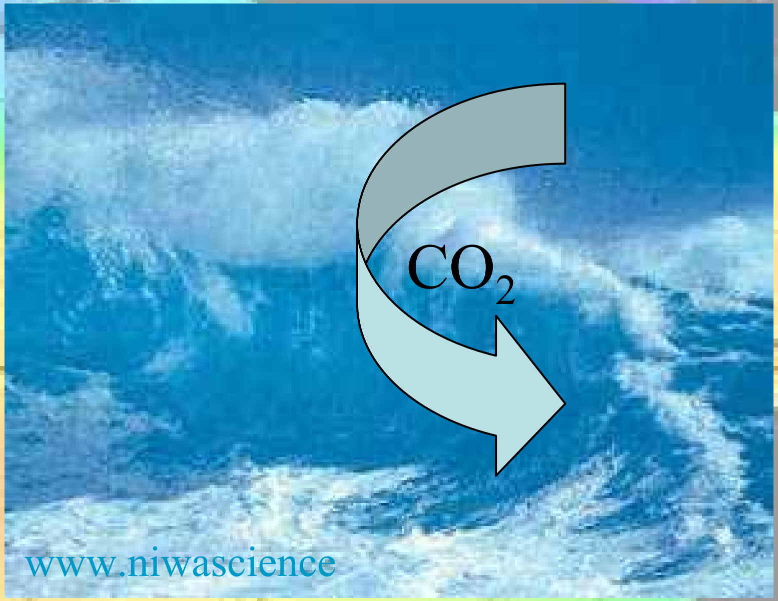
1. Human Population Growth
2. Overfishing
3. Coastal Development
4. Lack of Laws / Enforcement
5. Sedimentation (unnatural)
6. Lack of Education
7. Nutrient Enrichment
8. Algal Competition
9. Climate Change / Bleaching
10. Habitat Destruction
11. Tourism

36. Ocean Acidification

2004 Survey: 276 Coral Reef Scientists
Kleypas and Eakin (2007)

The Oceans and CO_2: Ocean Acidification

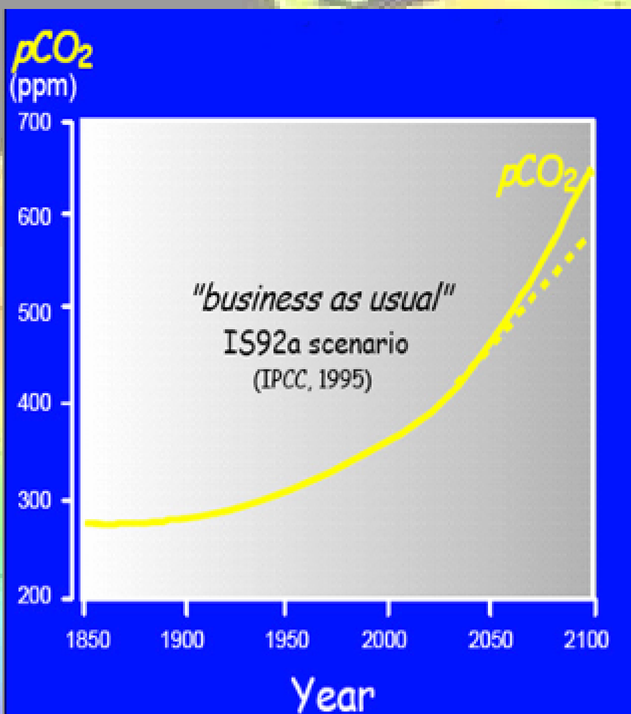


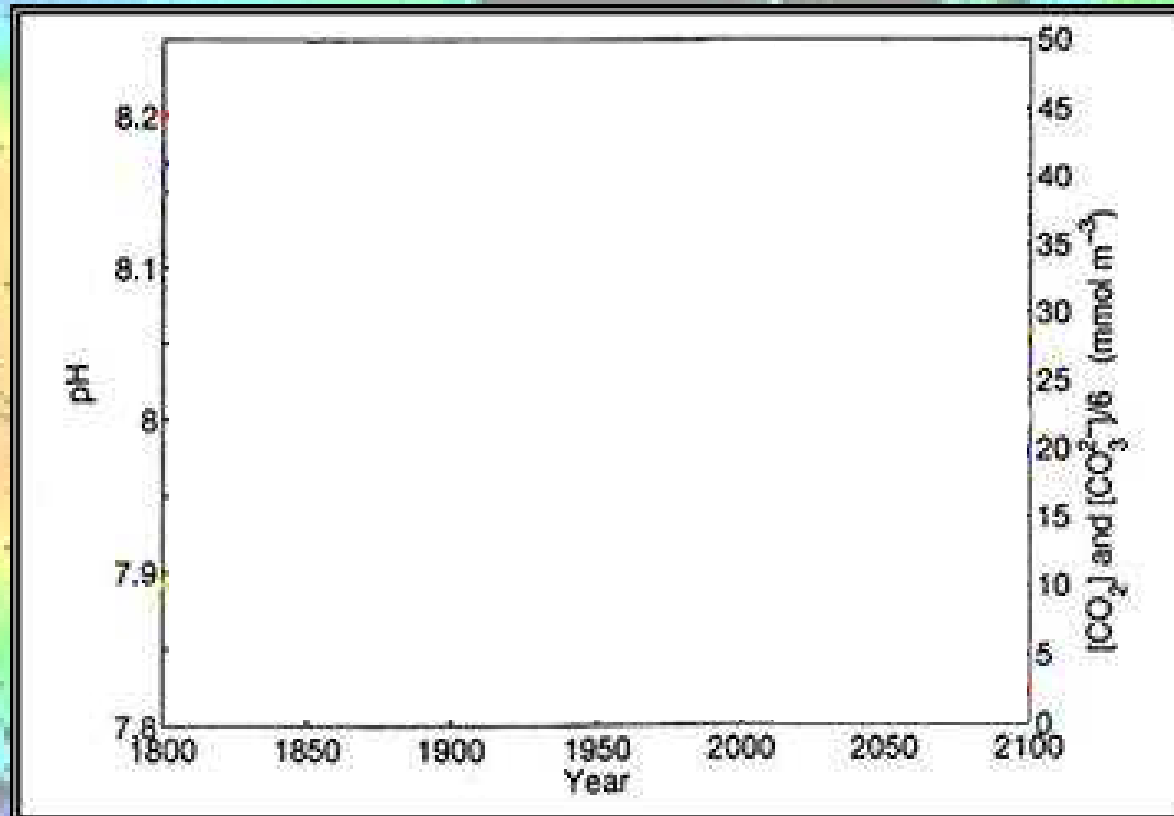


≈ 1/2 of total anthropogenic CO_2 taken up by the ocean,
> **25% each year**

http://coralreefwatch.noaa.gov

The Oceans and CO_2: Ocean Acidification



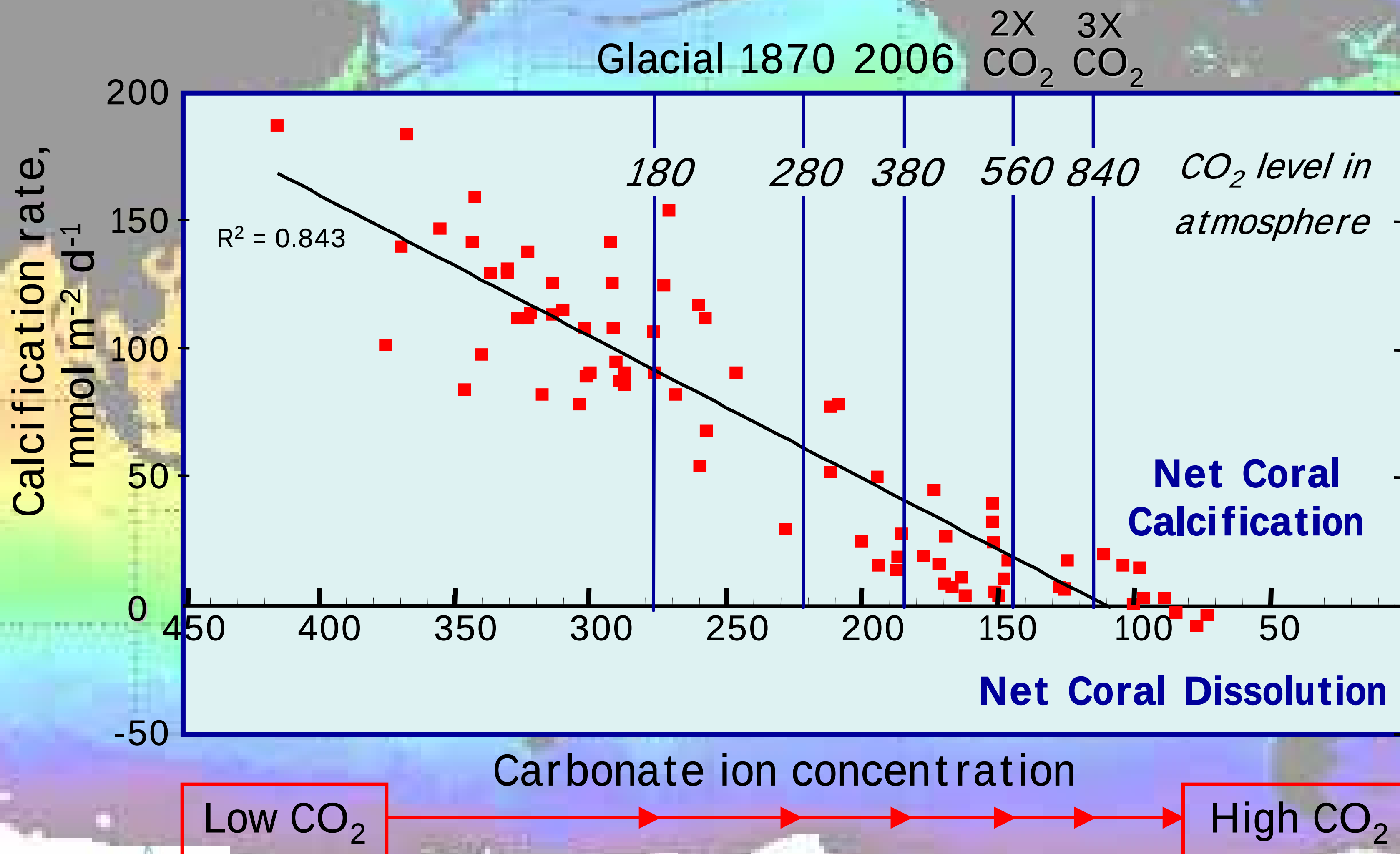


After Wolf-Gladrow et al., 1999

NOAA coral reef CONSERVATION PROGRAM

http://coralreefwatch.noaa.gov

Decreased Coral Calcification with Increasing Ocean CO_2



Langdon & Atkinson, (2005)

http://coralreefwatch.noaa.gov

Ocean Acidification:
Impacts on Corals and Reefs

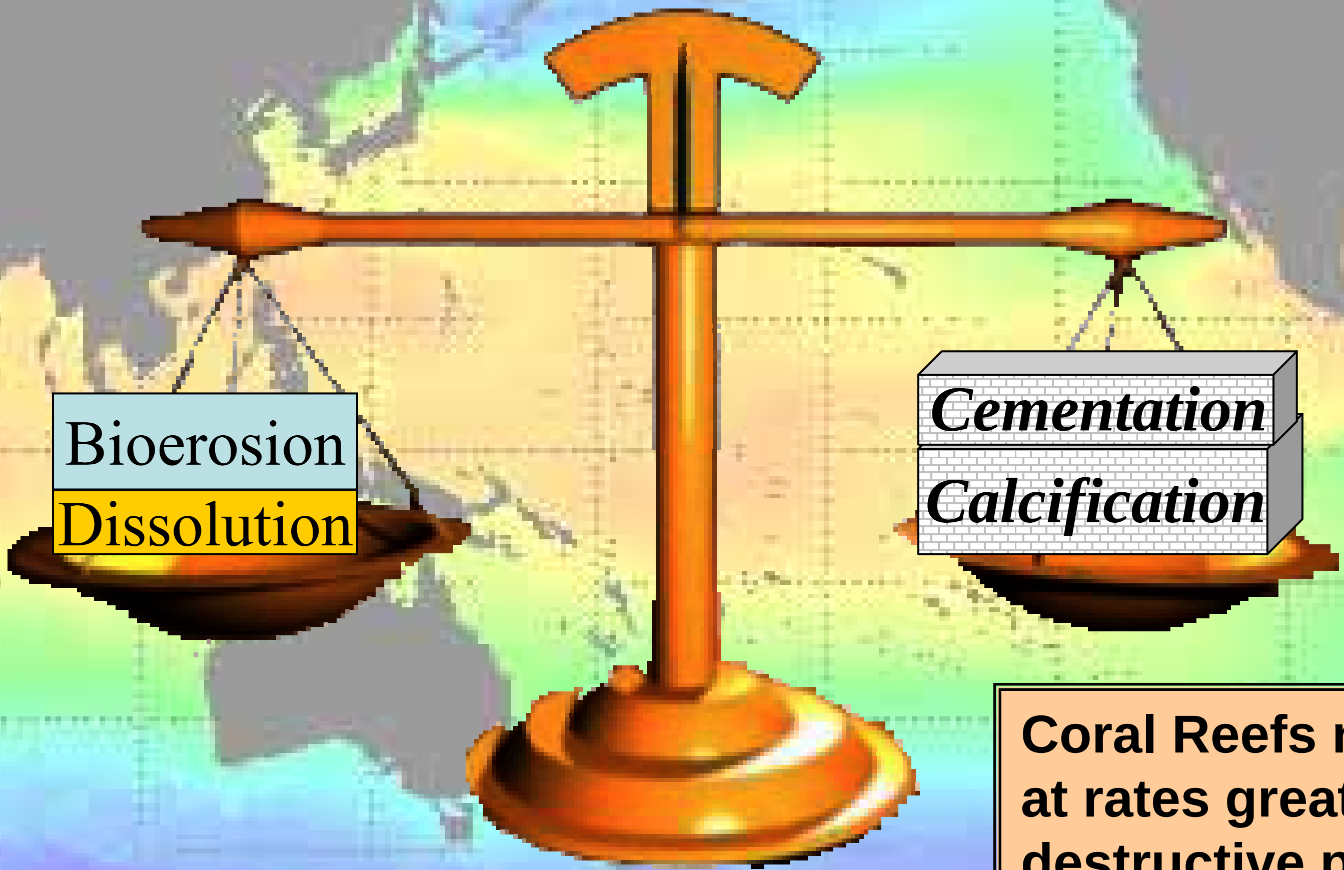
Three Options for Corals:

- Grow (extend) more slowly
- Build more brittle skeletons
- Divert energy from other processes (reproduction, healing damage, etc.)

Consequence:

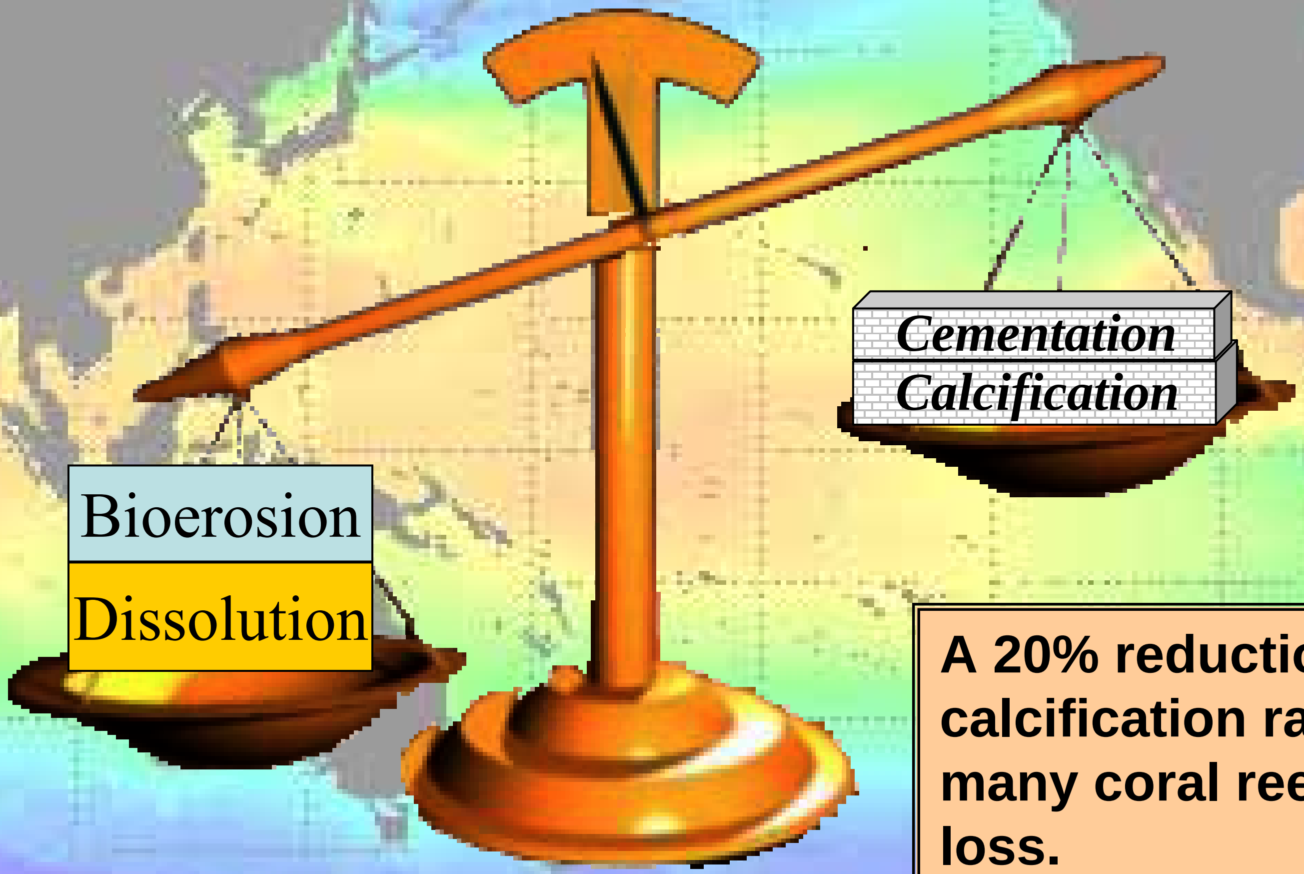
- Changed balance between construction and erosion
- Reduced ability to keep up with rising sea level

Coral Reef “Growth” in the Balance



Coral Reefs need to calcify at rates greater than destructive processes to grow.

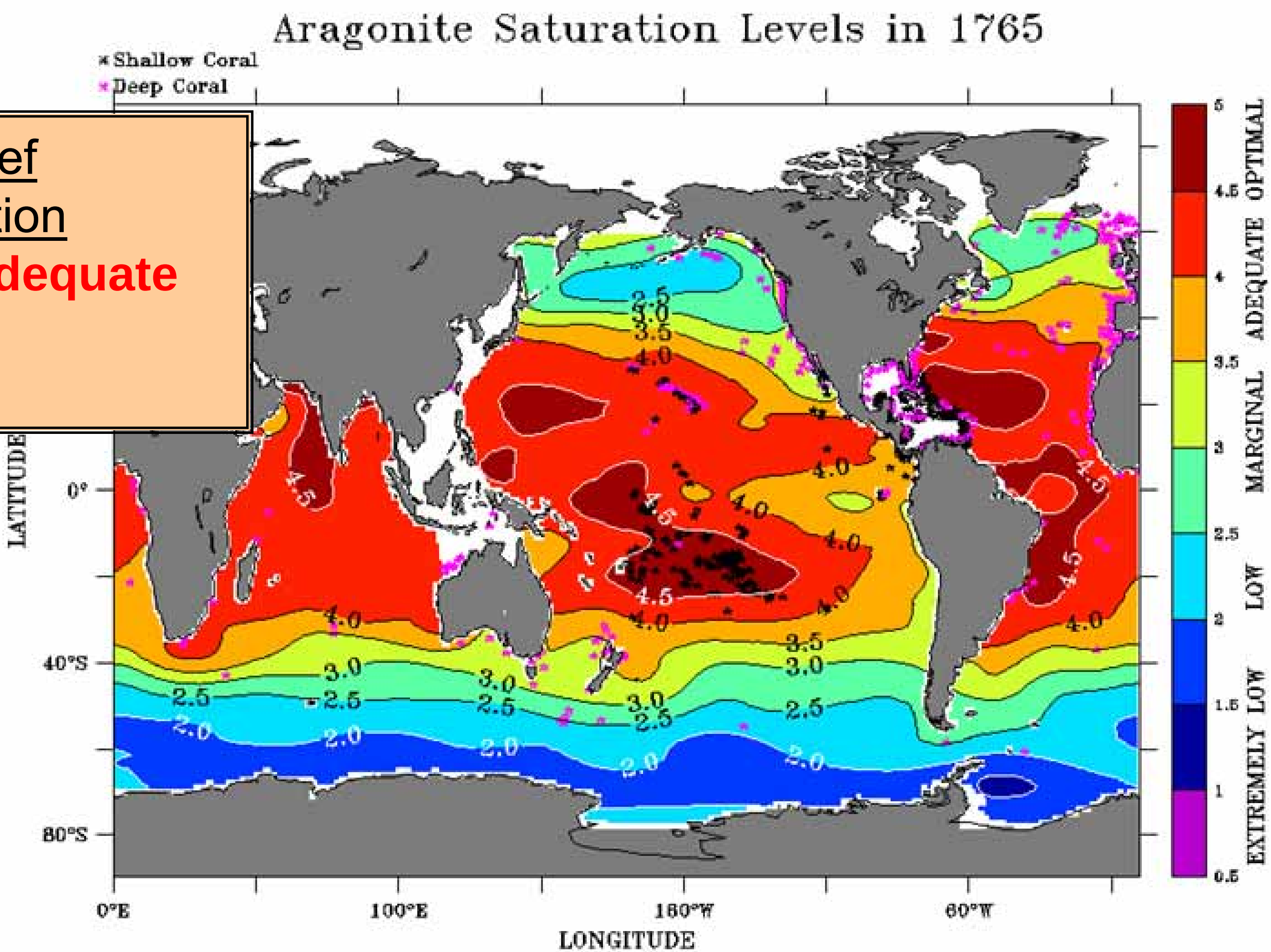
Coral Reef "Growth" in the Balance



A 20% reduction in calcification rate could push many coral reefs into net loss.

Future Changes in Reef Calcification

IPCC IS92a 'business-as-usual'



<u>Coral Reef Calcification</u>

- 1765 **Adequate**
- 2005
- 2100

After Feely et al (in press) with Modeled Saturation Levels from Orr et al (2005)

Future Changes in Reef Calcification

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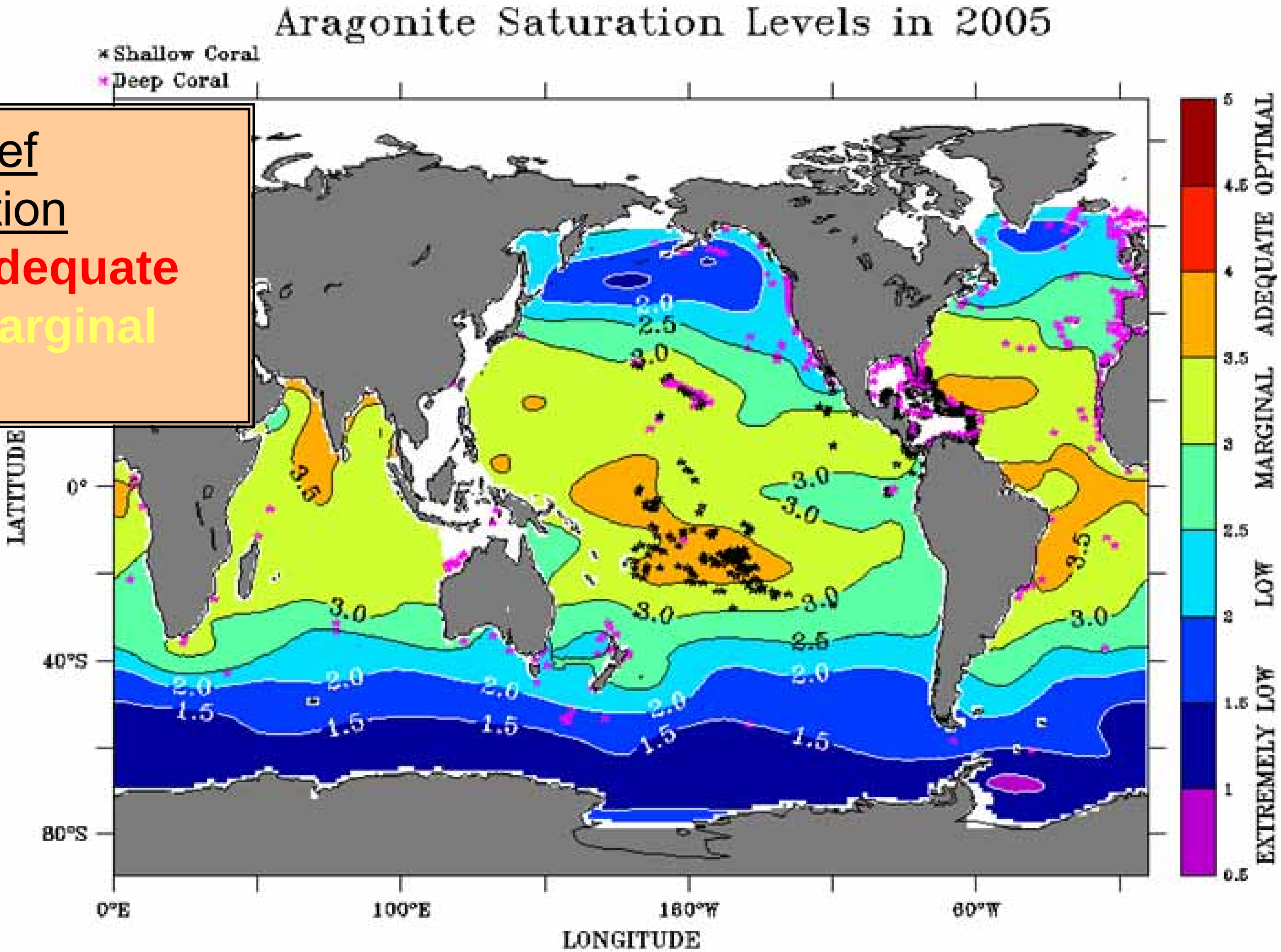

Coral Reef Calcification
- 1765 **Adequate**
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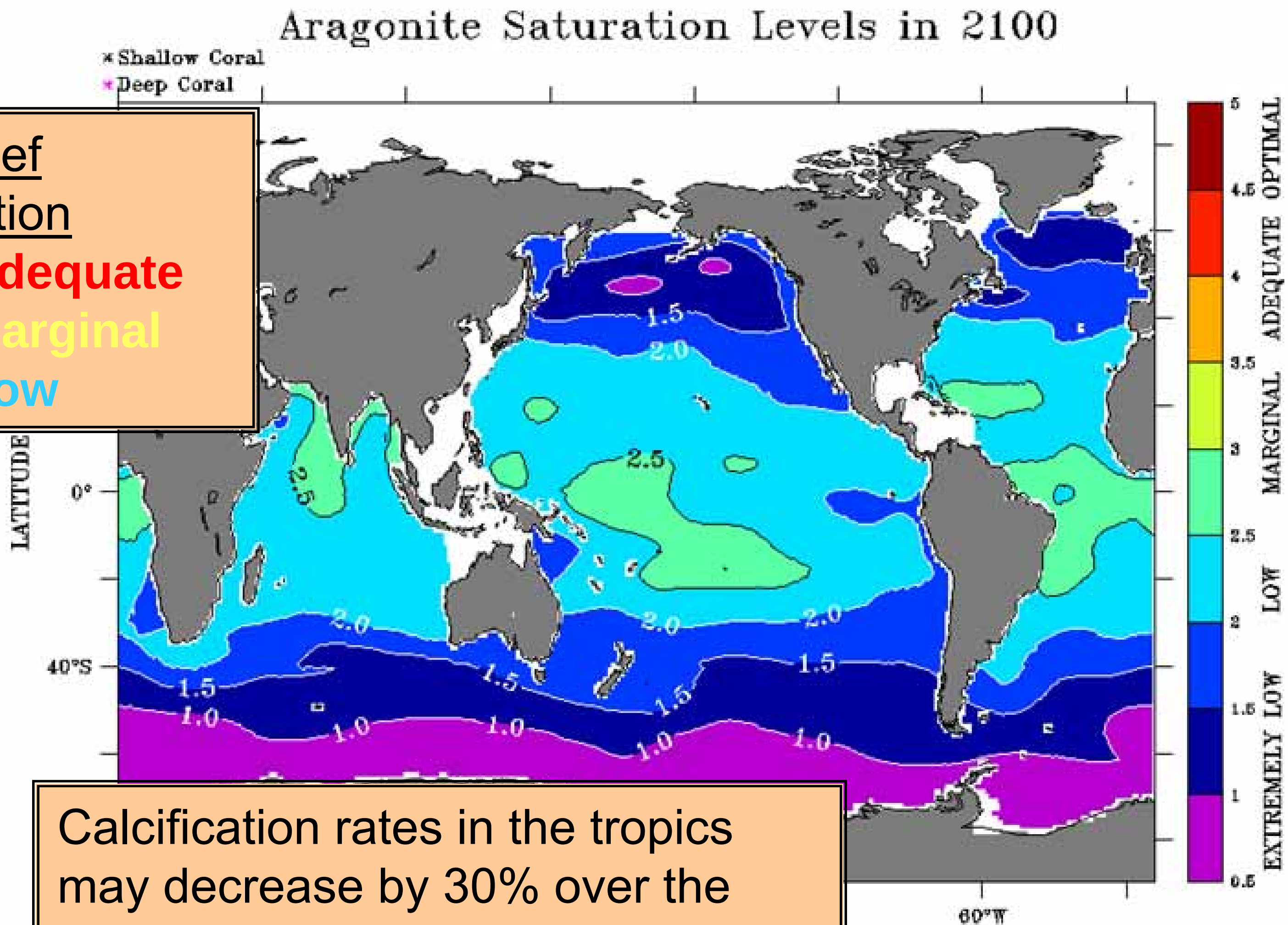


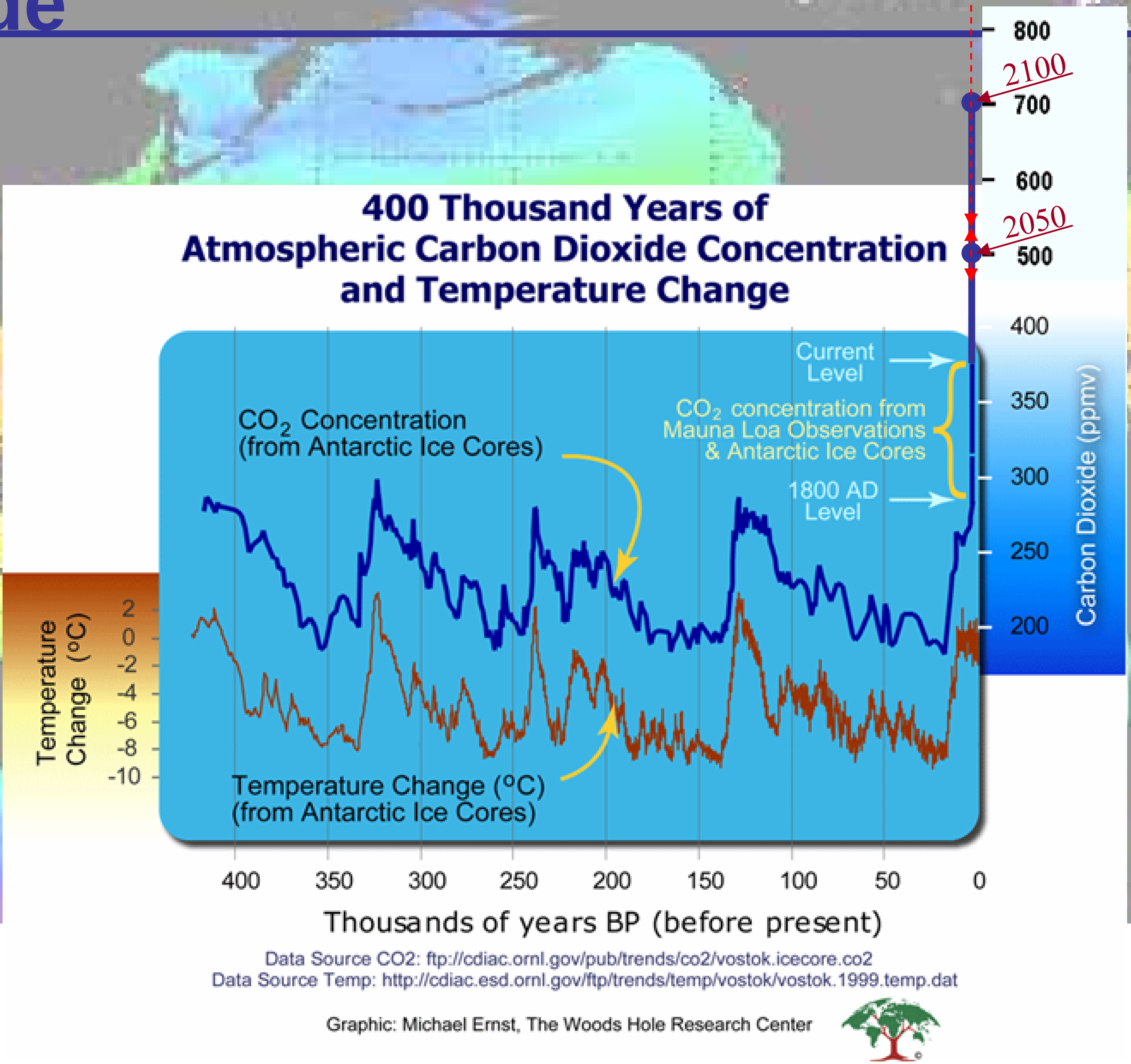
__Coral Reef Calcification__

- 1765 **Adequate**
- 2005 **Marginal**
- 2100 **Low**

Calcification rates in the tropics may decrease by 30% over the next century

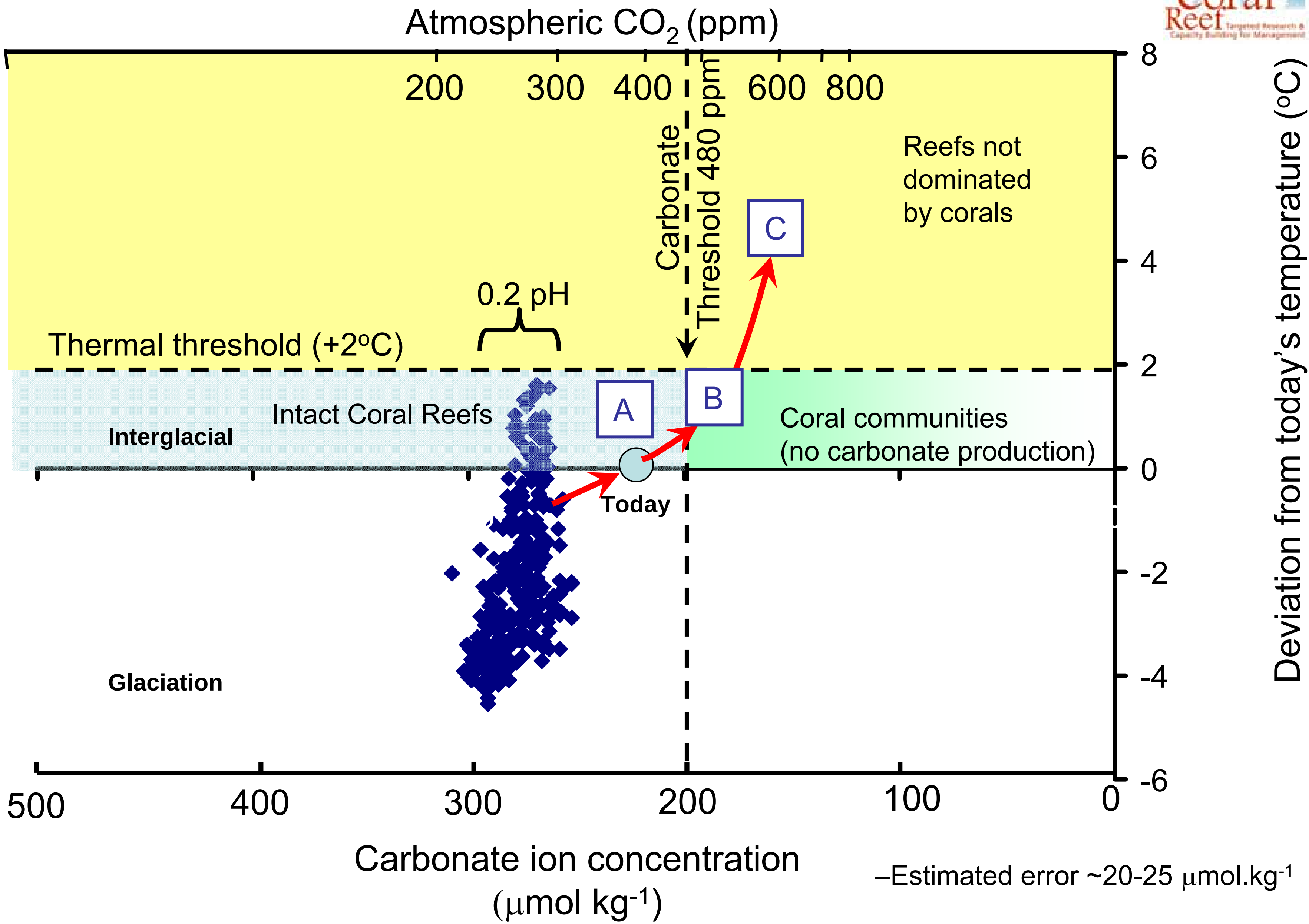
After Feely et al (in press) with Modeled Saturation Levels from Orr et al (2005)

Rising Atmospheric Carbon Dioxide



Current CO_2 highest in 650,000 years of ice core data and 24 million years from soil data

480 ppm $CO_{2\ atm}$ and 2°C: Thresholds for Coral Reefs



–Estimated error ~20-25 µmol.kg-1

www.gefcoral.org

Hoegh-Guldberg et al. 2007, *Science*

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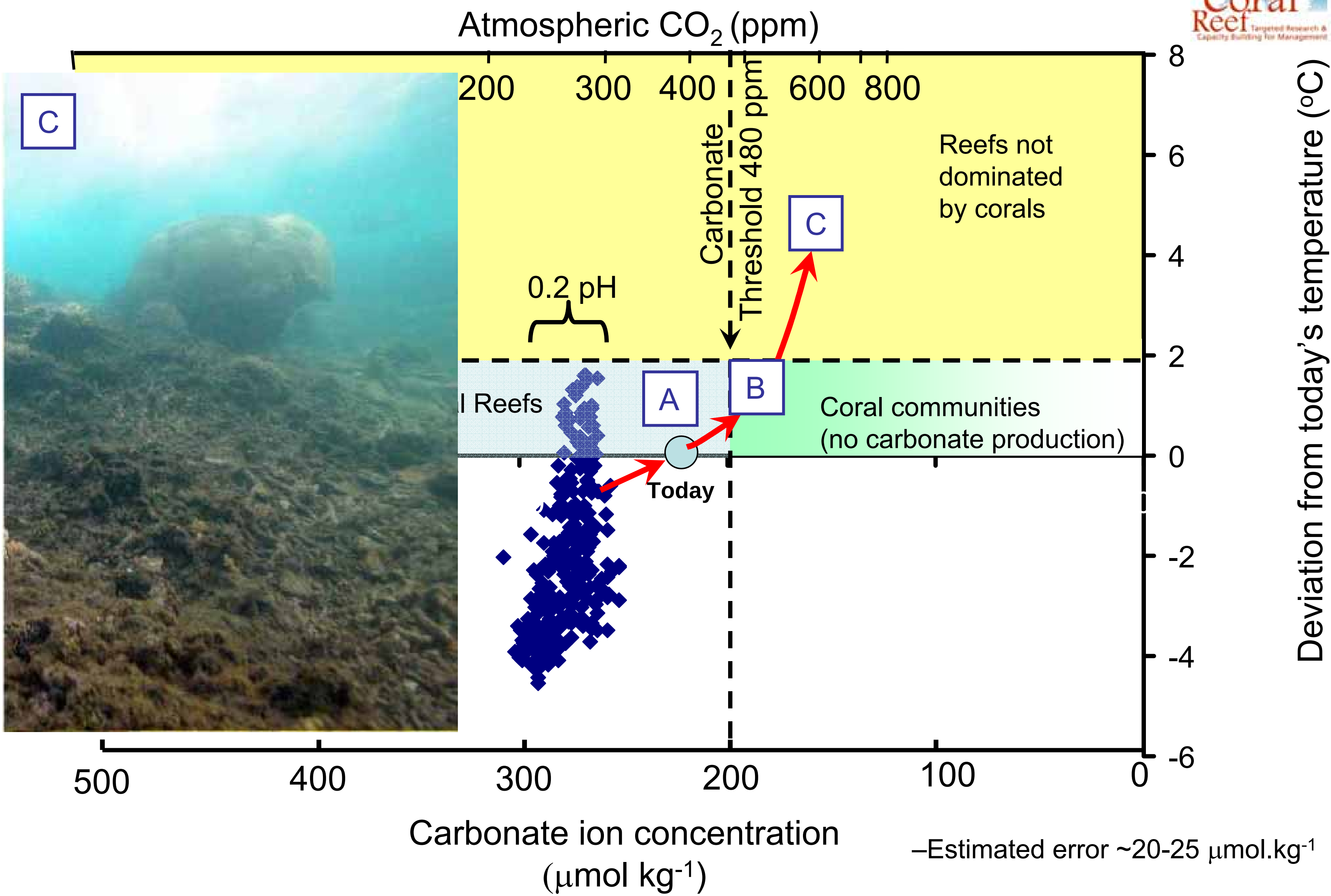

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www.gefcoral.org

Hoegh-Guldberg et al. 2007, *Science*

Thermal Stress Causes Mass Coral Bleaching

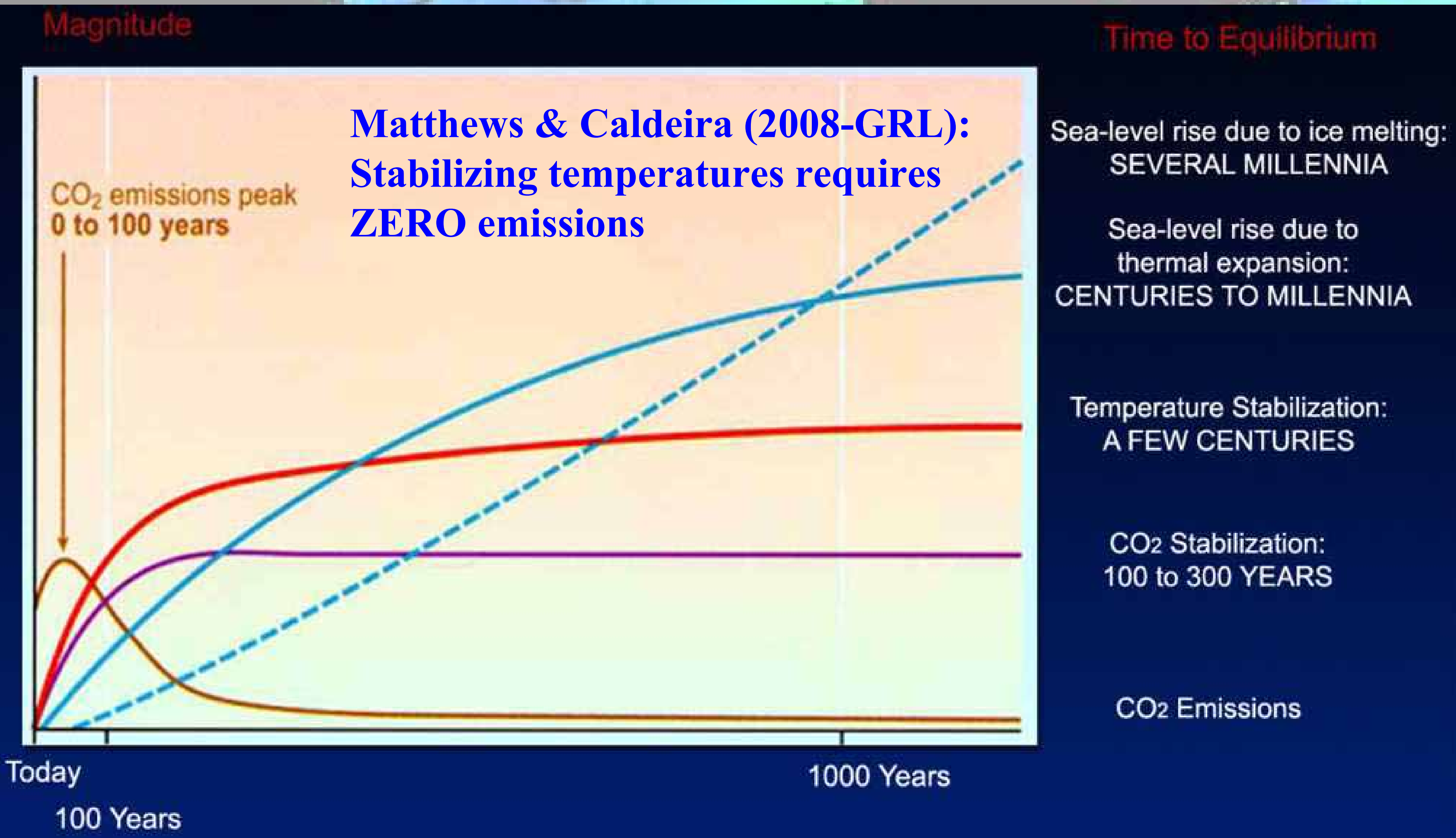
Thermal Stress Causes Mass Coral Bleaching

Thermal Stress Causes Mass Coral Bleaching and Mortality


Thermal Stress Causes Mass Coral Bleaching and Mortality
Ocean Acidification Eliminates Reef Structure

Two Part Solution:
1) Reduce Global CO_2 Emissions

Matthews & Caldeira (2008-GRL): Stabilizing temperatures requires ZERO emissions



Two Part Solution:
2) Reduce Local Stressors

Reducing Emissions Is Not Enough!

- Human Population Growth
- Overfishing
- Coastal Development
- Lack of Laws / Enforcement
- Sedimentation (unnatural)
- Lack of Education
- Nutrient Enrichment
- Algal Competition
- Climate Change / Bleaching
- Habitat Destruction
- Tourism
- Ocean Acidification

2004 Survey: 276 Coral Reef Scientists (Kleypas and Eakin 2007)

Are there signs of hope for bleaching?

Fortunately, the answer is yes.

Video from Peter Mumby, University of Exeter

This reef in Palau was devastated by bleaching in 1998.

Ten years later, the reef is covered with healthy corals.

If conditions are favorable, reefs can recover.

Are there signs of hope for bleaching?

After bleaching and death of corals….

Sensitive coral species are killed….

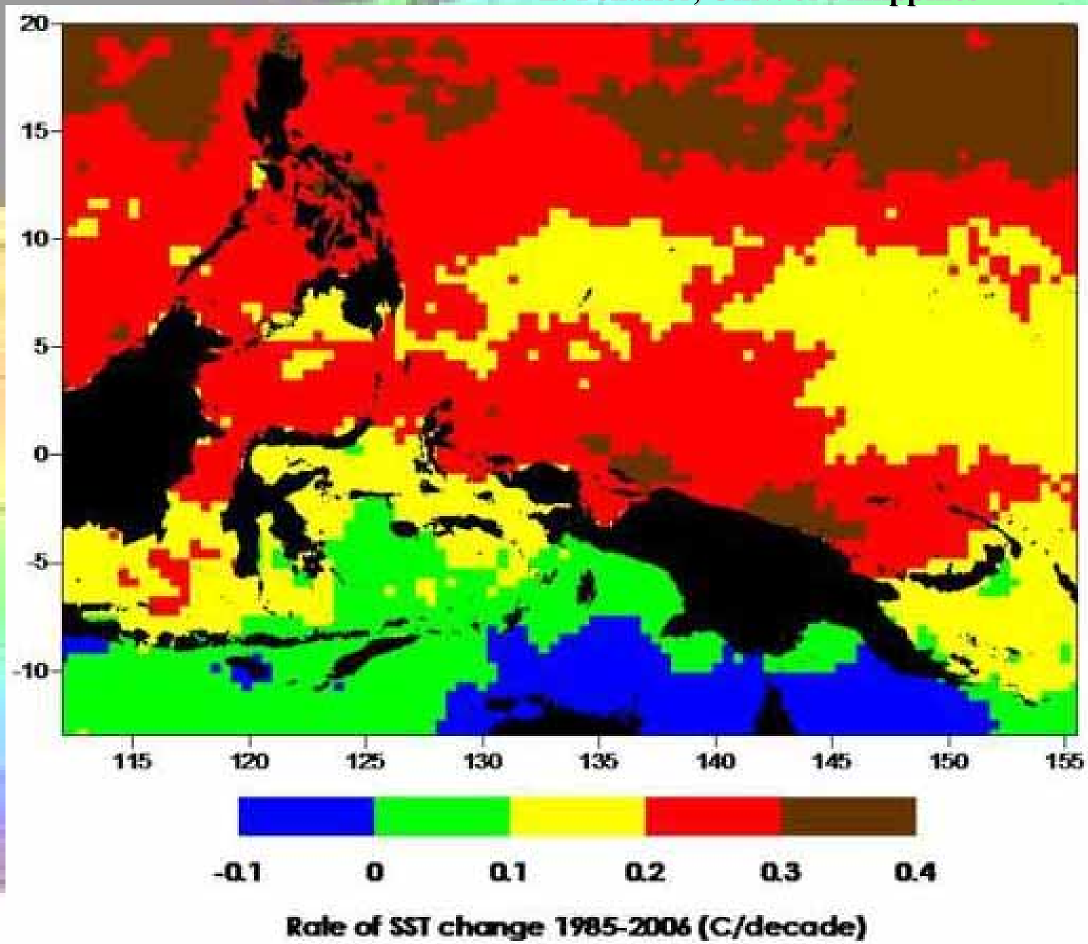
The corals that remain are the ones that can tolerate higher temperatures.

Result?

- Less diversity
- but increased reef resistance.

Are there signs of hope for bleaching?

E. Penaflor, Univ. of Philippines

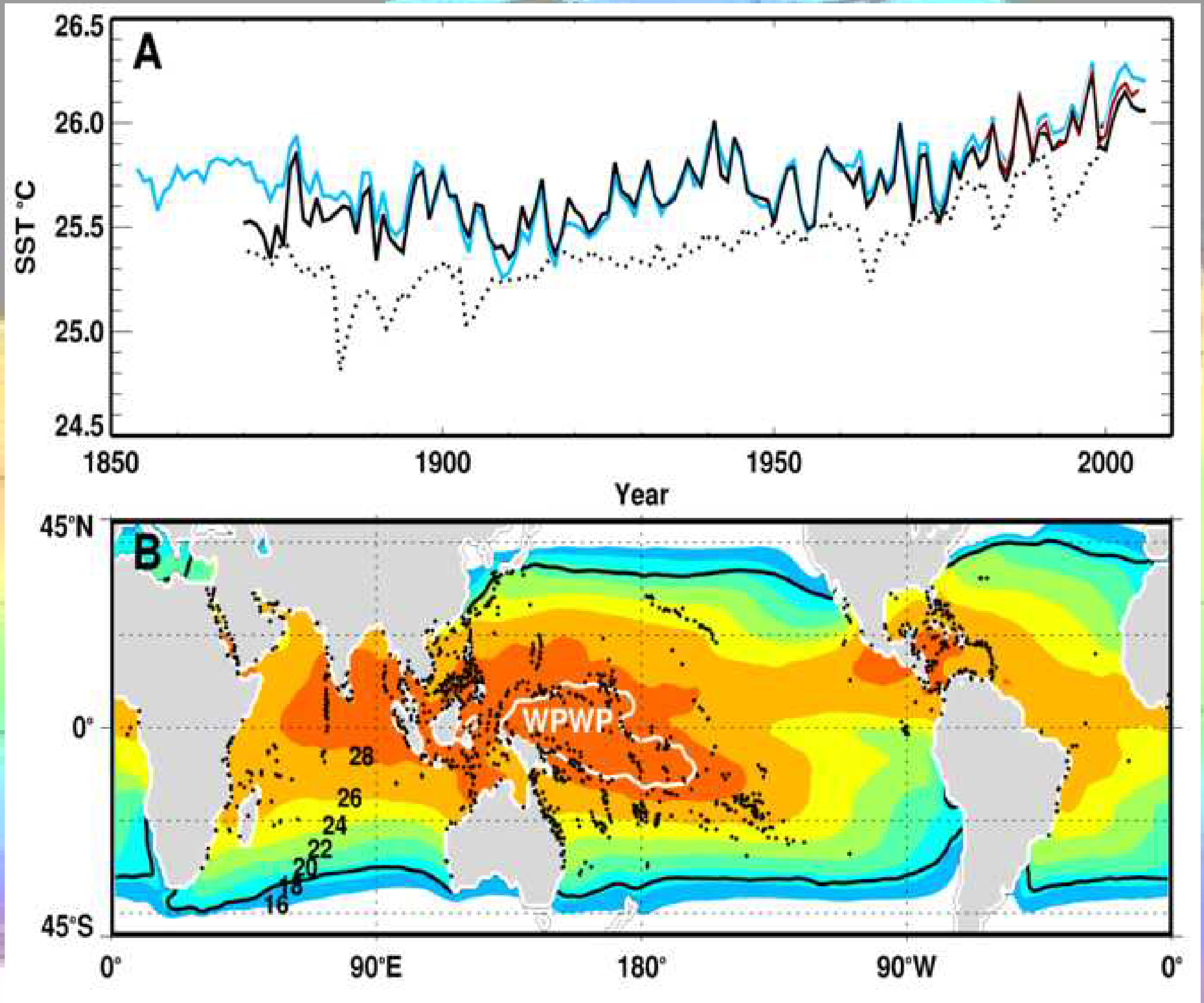


Some places are heating more slowly than others

- oceanography: warm pool and thermostat hypothesis

http://coralreefwatch.noaa.gov

The Western Pacific Warm Pool and the Ocean Thermostat

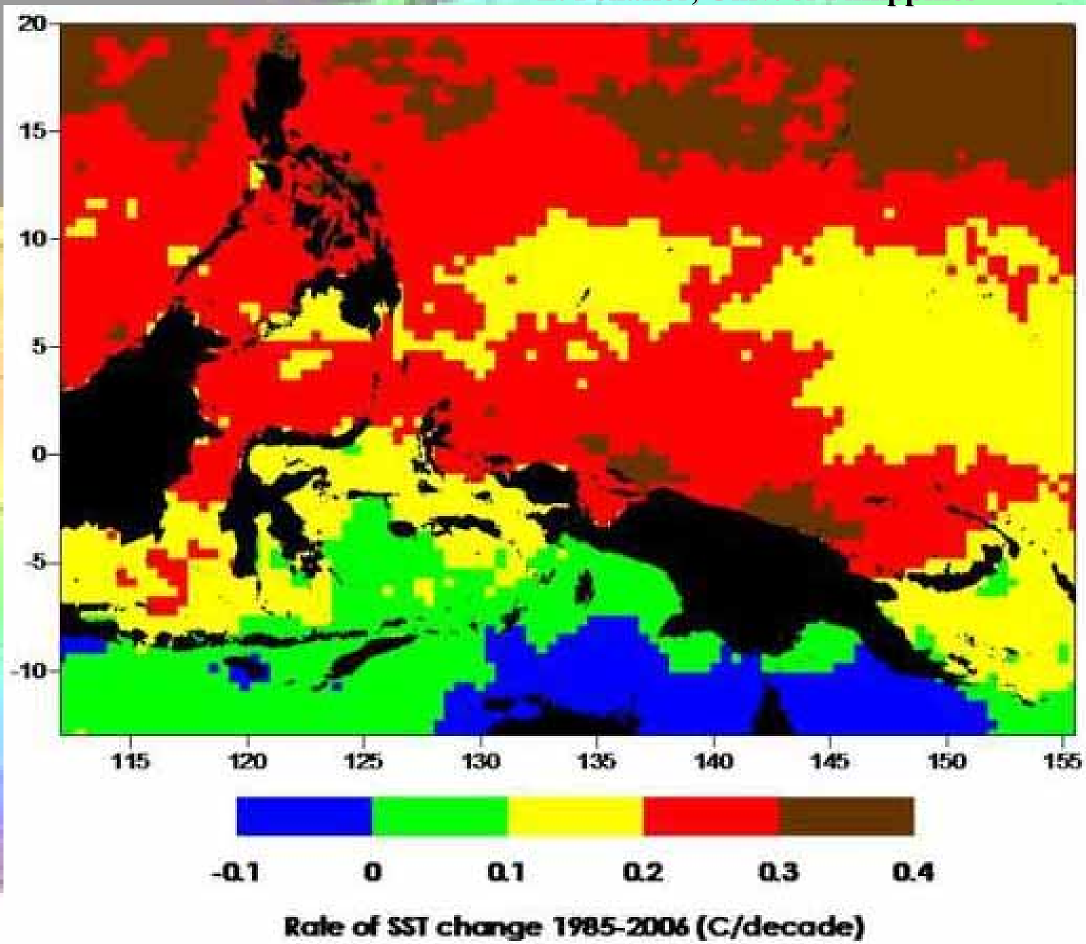


Kleypas et al. 2008, GRL

- Temperatures are rising globally
- Little warming in WPWP
- Less bleaching in WPWP

Are there signs of hope for bleaching?

E. Penaflor, Univ. of Philippines



Some places are heating more slowly than others

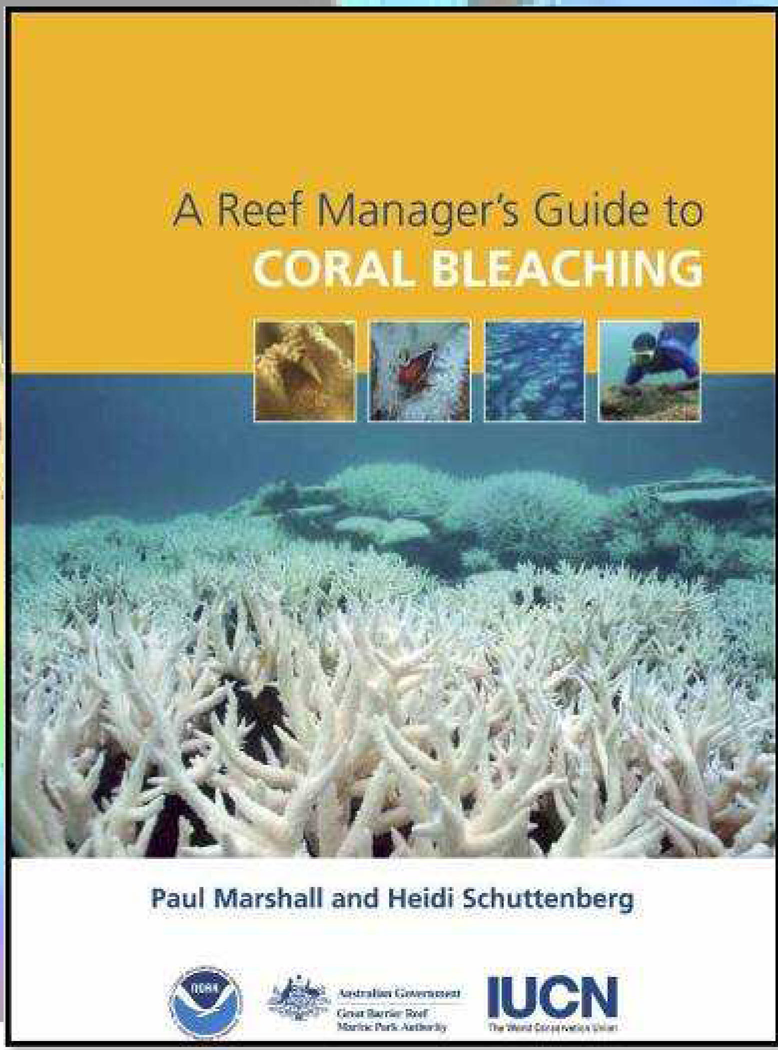
- oceanography: warm pool and thermostat hypothesis

- local hydrodynamics

May provide natural refuges

http://coralreefwatch.noaa.gov

Two Part Solution:
2) Reduce Local Stressors



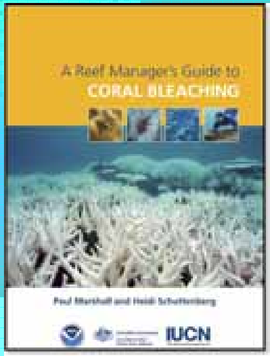
- **Strategies for management**
- **Responding to bleaching**
  - **short-term action**
- **Building long-term resilience**
  - **protecting resilient reefs**

Available at coralreef.noaa.gov

Short-term Opportunities for Coral Bleaching Management

Local managers can:

- Reduce bleaching
  - Reduce light stress
  - Cool reefs, increase mixing



Short-term Opportunities for Coral Bleaching Management

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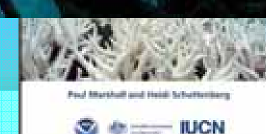
Quicksilver Connections

Small yet economically important effect



Short-term Opportunities for Coral Bleaching Management

Local managers can:

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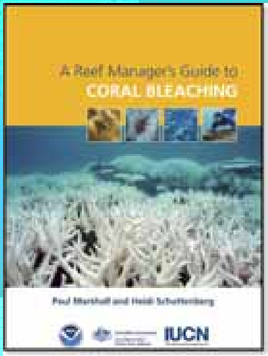
  - Cool reefs, increase mixing
- Increase survival
  - Improve water quality
  - Reduce disease prevalence



Short-term Opportunities for Coral Bleaching Management

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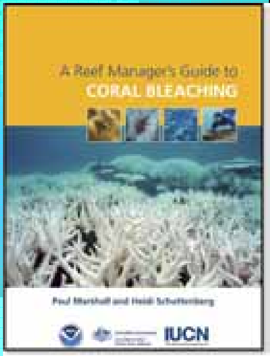
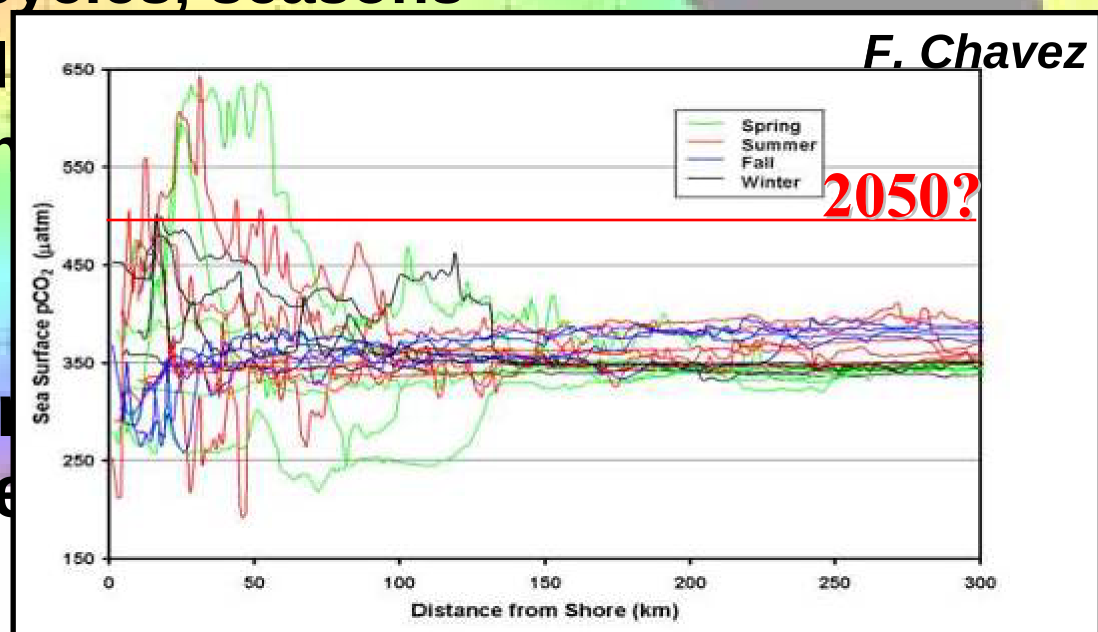


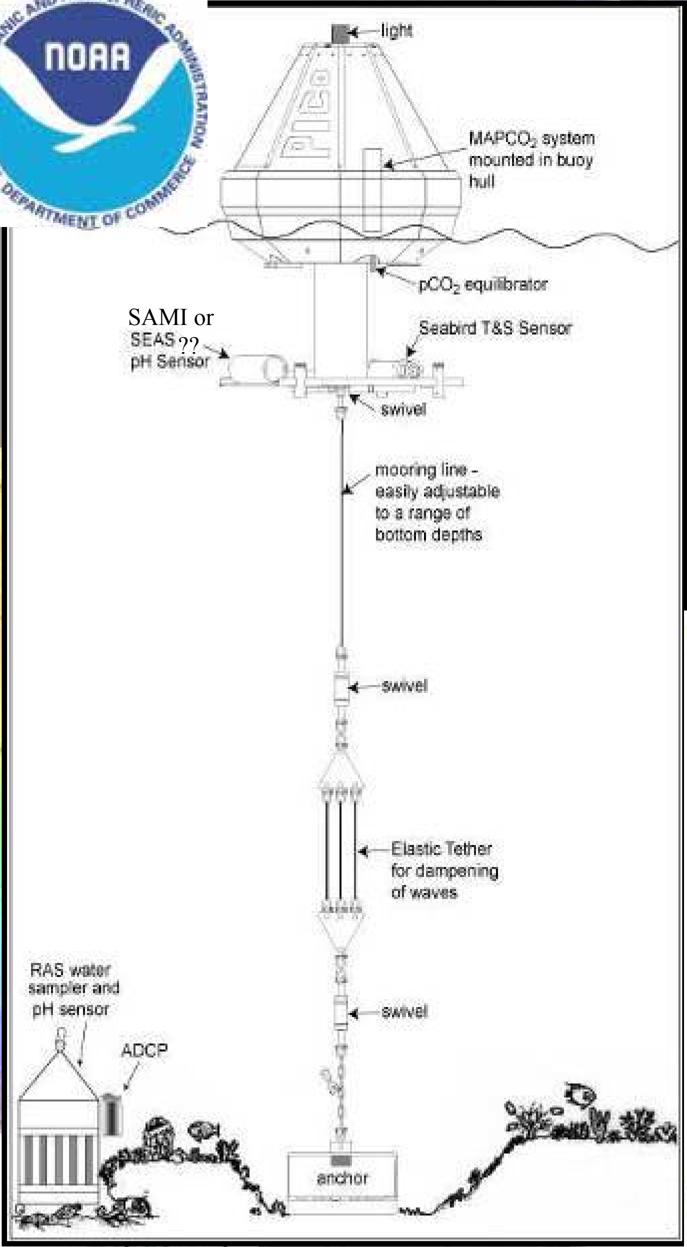
- Aid recovery
  - Coral fragmentation
  - Encourage recruitment
  - Protect ecosystem functions (herbivory)

Are there signs of hope for Ocean Acidification?

- **Coral calcification releases CO_2**
  - **calcification causes net pH decline**
- **pH varies naturally on reefs:**
  - **over days, tidal cycles, seasons**
  - **Can corals handl**
  - **Might this help th acidification…?**
- **Still poorly under reveal other hope**

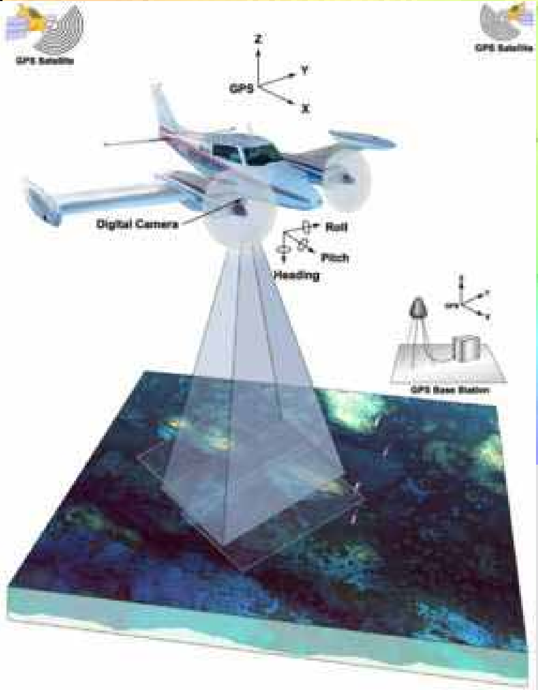


Ocean Acidification Test-Bed



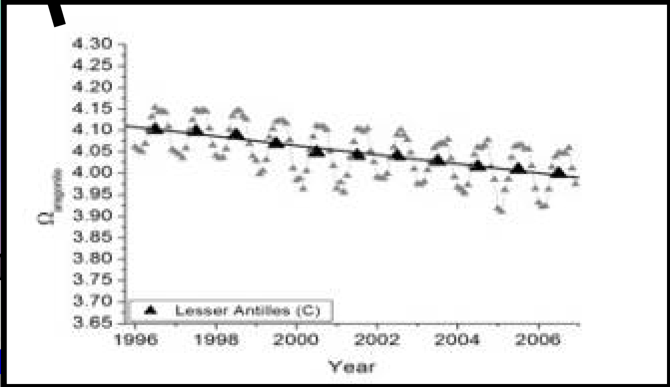
FY08-FY12 Project Goals

1. **Standardize approach and methodologies**
2. **Identify critical thresholds, impacts, and water chemistry trends**
3. **Characterize the temporal and spatial variability in carbonate system parameters**
4. **Ecological forecasting of OA stress to reefs.**



Ocean Acidification of the Greater Caribbean Region

Modeled fields of annual mean aragonite saturation state, Gledhill et al. (in review)



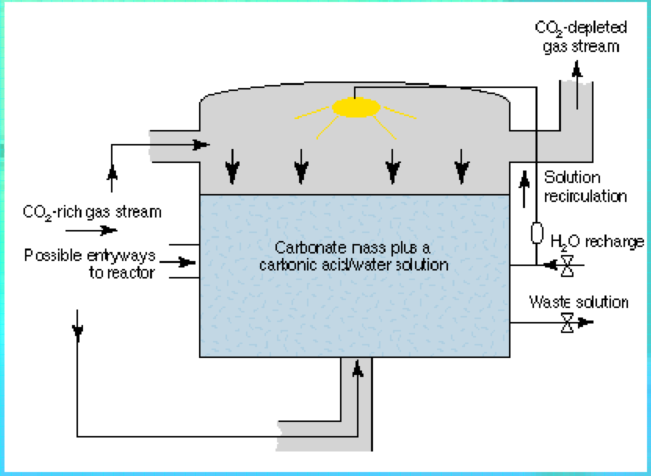
•Satellite and in situ observations are being coupled to model changes in surface ocean chemistry as a consequence of "ocean acidification".

•The mean Ωarg is declining at a rate of -0.12 ± 0.007 Ωarg decade-1 (r2 = 0.97, RMSD = 0.007, p<0.0001) over the past decade.

A Reef Manager's Guide to Ocean Acidification

Local managers can ?

- Increase CO_3^{2-}, HCO_3^-
  - CO_2 sequestration / Accelerated Limestone Weathering? (Rau et al.)
  -



- Increase survival
  - ?
- Aid recovery
  - ?

Key Messages:

- **Coral reefs threatened by rapid rise in temperatures, ocean acidification**
- **Likely thresholds of ≈ +2°C, 500 ppm $CO_{2\ atm}$**

- **Risks are huge**
- **2 actions needed <u>now</u>:**
  - **Reduce emissions**
  - **Reduce local stress**
- **There is hope, but we need to work on solutions**

Thank You


NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE
Coral Reef Targeted Research & Capacity Building for Management
NOAA CORAL REEF WATCH
NOAA coral reef
CONSERVATION PROGRAM